University of Canterbury Department of Physics & Astronomy

Mt John University Observatory

Mt John Photometrics CCD System

Use and Performance Note Number 1

DESCRIPTION OF THE SYSTEM

W. Tobin

1990 December 17

These Notes are intended for guidance only: individual observers have the sole responsible for the integrity of their own data. Users of the CCD system are encouraged to summarize the performance that they obtain in a Note in this series. Contact Dr. W. Tobin to be allocated a series number.

In 1988 December the Department of Physics at the University of Canterbury took delivery of a Photometrics 3000 cryogenic CCD system. The system was purchased through grants from the University Grants Committee, the New Zealand Lottery Board, the University of Canterbury and the Department of Physics to Dr W Tobin as Principal Investigator. To obtain an export license from the US Department of Commerce it was necessary to certify that the system will be used 'in New Zealand only, and for scientific research in the astronomy of natural celestial phenomena'. Users must comply with these restrictions.

Users should refer to the 'Photometrics 3000 User's Manual' version 3.01, October 1987, for fuller details of the equipment detailed below.

The system comprises:

- CH210 — cryogenically-cooled, bottom-looking camera head, with a Thomson CSF TH7882 CDA CCD chip installed, overcoated with Metachrome II for enhanced ultraviolet response. Attached to the dewar is a 1-inch inside-diameter Uniblitz shutter and a ring of green preflash LEDs. Various nitrogen fill ironmongery is also supplied.

- CE200 — camera electronics unit, with 50 kHz analogue to digital conversion (14 bits).

- PM3000 — digital image acquisition and processing system, based on a Heurikon Corporation HK68 microcomputer board and HSE10 enclosure, comprising
  - Motorola 68020 CPU with 68881 FPP
  - Four serial interface ports
  - One general purpose SCSI port
  - One megabyte of program RAM
  - 55 megabyte hard disk (Fujitsu M224XAS with Adaptec Inc. ACB-4000 SCSI disk controller)
  - 720 kilobyte Mitsubishi Electric MF504B-3 5¼" floppy diskette drive
  - 40 megabyte DC 2000 ¼" cartridge tape drive
  - Nine-slot MULTIBUS I chassis
  - Forth operating and image acquisition system
  - Image display module, with mouse
  - 8 megabyte image buffer RAM
  - diverse cables
  - Human Designed Systems HDS 3200 terminal (VT220 and Tektronix 4040/4014 capabilities)
  - Electrohome high-performance RS-170 monochrome video monitor.

Users should refer to the 'Photometrics 3000 User's Manual for the Forth Programming System,' version 3.01, October 1987, for fuller details of the software provided by Photometrics.

Subsequently the following additional computer hardware has been acquired and interfaced:

- Panasonic KX-P1081 impact dot matrix printer and KX-P17 RS232C adapter.

- M4 9903 1600 bpi 9-track, half-inch streaming tape drive

- M4 SCSI option Streamer Buffered Interface (purchased with funds provided by the Carter Observatory, Wellington)

The 9903 streamer provides the normal method of recording and transporting images. Non-Canterbury users should ensure they bring an adequate supply of tapes with them to the mountain.

When used with the 1-metre McLellan Telescope a VT220 terminal and RS170 video monitor are available on the observing floor for command and image-display purposes.

Various racks, trolleys, etc., have been constructed to ease use and/or manipulation of the CCD. It is also possible to connect the 'PETSET' time box to any of the four serial interface ports for checking the drift of the CCD internal clocks. A significant amount of additional software has been written to facilitate observing, and to provide fuller information in each image header.

A very-similar Photometrics CCD system has been installed at the University of Toronto Southern Observatory (UTSO). The performance of the Mt John system is in many ways similar to that at UTSO, and Mt John users are recommended to read the published description of the UTSO system (McCall, M.L., English, J., Shelton, I.: 1989, *J. Roy. Astron. Soc. Canada* **83**, 179-206.

University of Canterbury Department of Physics & Astronomy

Mt John University Observatory

Mt John Photometrics CCD System

Use and Performance Note
Number 2

EVALUATION OF THE LINEARITY OF THE MT JOHN CCD

K. Pollard

1989 September

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Evaluation of the linearity of the Mt John CCD

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Mt John University Observatory,
Department of Physics,
University of Canterbury,
Christchurch,
New Zealand.

September 1989

1 Introduction

A charge-coupled device (CCD) imager is a MOS (metal oxide semiconductor) optical detector. When a CCD chip is exposed to light, charge accumulates in the potential wells of the two-dimensional imaging area called the parallel register. Charge can accumulate over an extended period of time – the total amount of accumulated charge is proportional to the product of the light intensity and the exposure time. The aim of the procedure reported here is to investigate the linearity of the MJUO TH7882 CDA chip and determine over what range of intensities the CCD is linear.

2 Experimental procedure

2.1 Stable light source

The stabilised diffuse light source consists of a 'top hat' arrangement and the control box. The top hat contains an arrangement of different coloured LEDs that illuminate the depolished crown of the hat. The arrangement consists of infra-red, red, blue and green LEDs where only one set of LEDs can be selected at any one time. The LEDs are powered by a controlled stabilised power supply. By altering the current in to the LEDs the intensity can be varied. The current is set by a coarse and a fine adjustment.

The six red LEDs (wavelength 655 nm), mounted in a circular pattern behind a depolished window in the top hat, were used for the testing of the linearity. The brightness was set at medium on the coarse scale and 2.0 (outer scale) for the fine adjustment so that a twenty minute exposure would give a close-to-saturation level image on the CCD. The LEDs were turned on and left overnight to stabilise before use. Because the response of the the LEDs is slightly temperature dependent, the top hat, CCD dewar and electronics unit were set up in the Phys201 wet darkroom which had a reasonable temperature constancy. The Photometrics 3000 computer and the observer were in the dry darkroom next door. The drift of the LEDs was monitored by taking a 10 second reference observation between each set of timed observations. All lights on the CE electronics unit were taped over to ensure no light was being detected from other sources. The control box contained an accumulator which could be recharged by plugging the box into the mains.

2.2 CCD camera

The CCD chip was cooled to an operating temperature of -111.9 °C. The camera head was mounted on an optical bench at a distance of about 0.5 meters from the stable light source. A 50mm Pentax camera lens was then attached to the camera head and focussed.

3 Observations

An observation is initiated by typing: 't' obs , where t is the duration of the exposure in deciseconds. This command closes the shutter, clears the CCD array twice, opens the shutter for the specified time and reads the CCD out. Each set of timed observations of the stable light source by the CCD consisted of:

- a dark exposure
- a first observation (a)
- a second observation (b)

The dark frame contained the standard bias component as well as the dark signal. The minimum exposure was 0.5 seconds and the exposure length was doubled for each subsequent exposure up to a maximum of 1024 seconds. A further exposure of 1260 seconds was made to take the CCD image up close to saturation level. The dark CCD frame was inspected for cosmic ray events. The dark was then subtracted from both the first and second observation and both images were saved on mini data cassette tape.

4 Image Analysis

The dark-subtracted images were analysed using the PM3000 `video monitor`. The full frame image was displayed with intensity varying linearly between two selected values of minimum and maximum. A reasonably constant-intensity region of the stable light source was chosen near the middle of the circular array of LEDs. The FORTH commands available in the software allowed a 100×100 pixel box to be displayed at the chosen region (center column 215 row 185) of the light source ('sb' and 'pcur') together with information about the intensity inside the box. The 'stats' command gave values of maximum, minimum and mean intensity and the rms of the mean intensity over the 10000 pixels. Thus, in this way, an average was obtained over the same region of the constant light source for differing exposure times.

5 Results

Figure 1 plots the signal levels in the interspersed 10 second exposure against the logarithm of the exposure time that preceded them. The intensity of the LEDs is seen to vary by less than 2% except for perhaps the 1260 second exposure. The counts obtained were then scaled to account for the fluctuations in these reference exposures. The results obtained from the analysis are given in Table 1 below:

Table 1 : Reference Counts

log(exposure time)	counts (per 10 seconds)
0.00000	128.341
0.30103	128.503
0.60206	128.501
0.90309	128.434
1.20412	128.378
1.50515	128.298
1.80618	128.248
2.10721	128.081
2.40824	127.845
2.70927	127.457
3.01030	126.531
exposure time (seconds)	**counts (ddu)**
1.0	13.317
1.0	13.314
2.0	26.124
2.0	26.147
4.0	51.777
4.0	51.792
8.0	102.839
8.0	102.866
16.0	205.239
16.0	205.203
32.0	410.103
32.0	410.125
64.0	820.006
64.0	820.073
128.0	1639.818
256.0	3282.590
256.0	3282.454
512.0	6574.723
512.0	6571.740
1024.0	13200.570
1024.0	13188.648
1260.0	16136.386
1260.0	16134.473

The 0.5 second exposures showed electrical pickup (seen as periodic 'waves' on the displayed image) and also had a comparatively large uncertainty, in part due to shutter speed variations which make up a not-insignificant part of the exposure time. The 0.5 second exposure was therefore not included in further analysis. A weighted least-squares linear progression was made on the data set. The weighting procedure allows the one second exposure to carry as much weight as the 1024 second exposure. The regressed straight line obtained was plotted together with the experimental points on a graph of exposure time *vs.* counts (see figure 2). The data set was then divided into two halves. A linear regression was done on each half of the data and the experimental points were again plotted together with the regression line (see figures 3 and 4). A log(exposure time) *vs.* log(counts) was also linearly regressed and plotted (see figure 5).

The results obtained from the weighted linear regression are shown in Table 2 below:

Table 2 : Regression Parameters

Input data	Regression coefficient	Regression constant	Figure
linear time	12.837	0.385	2
linear time (first half)	12.798	0.530	3
linear time (second half)	12.842	-2.251	4
log time	0.995	1.118	5

6 Conclusions

The light source used is seen from the graph to be stable to about 1.5% over the time of the observations. The counts obtained for each exposure was scaled to take account of these fluctuations. For exposures less than one second, low-level electrical pickup and shutter speed variations caused larger percentage experimental uncertainty. The results of the weighted linear regression (using slope of log graph) shows that the MJUO CCD is linear over the range of intensities 10 ddu (digital data units) to 15900 ddu to better then 0.5%.

Figure 1

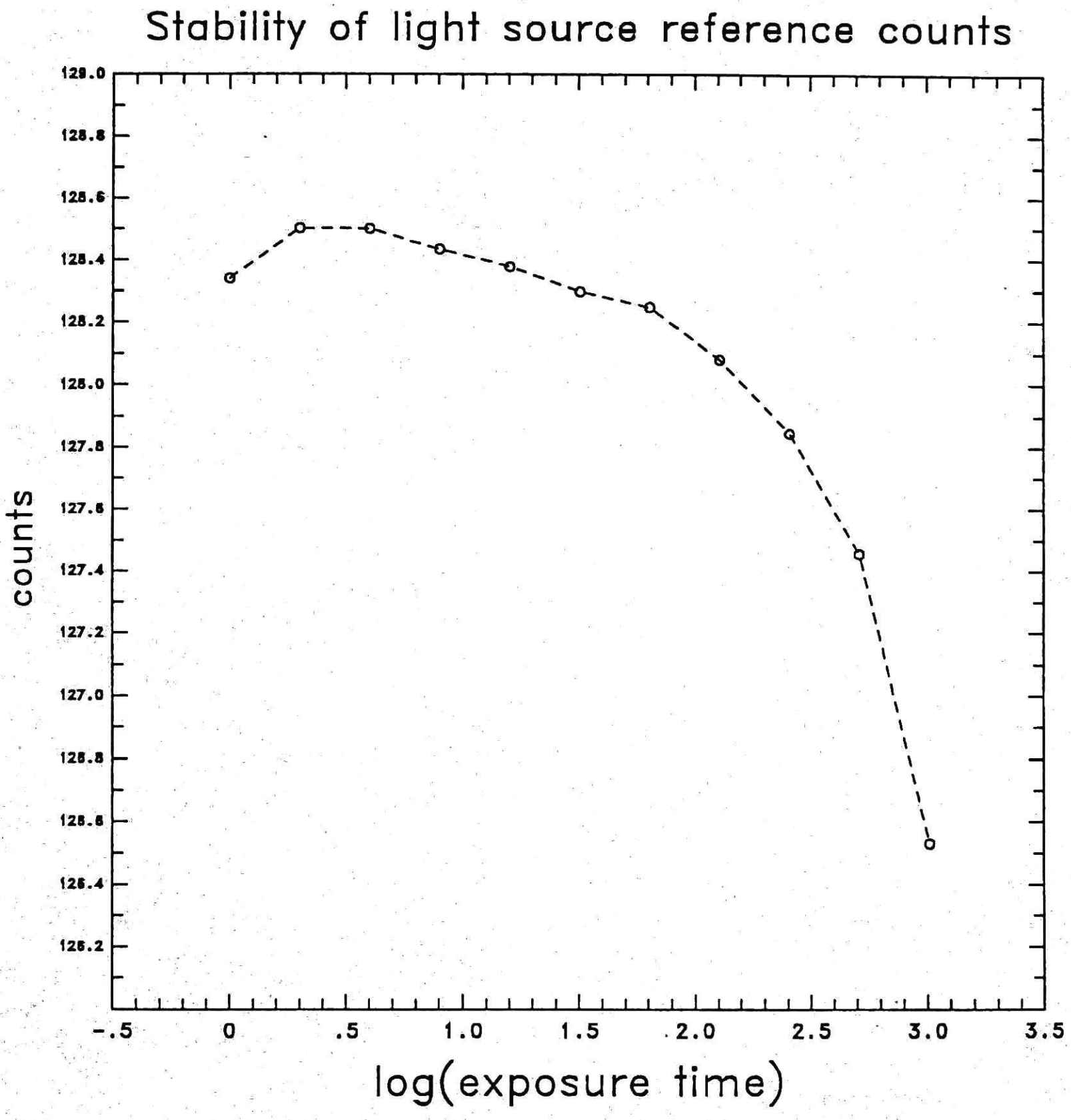
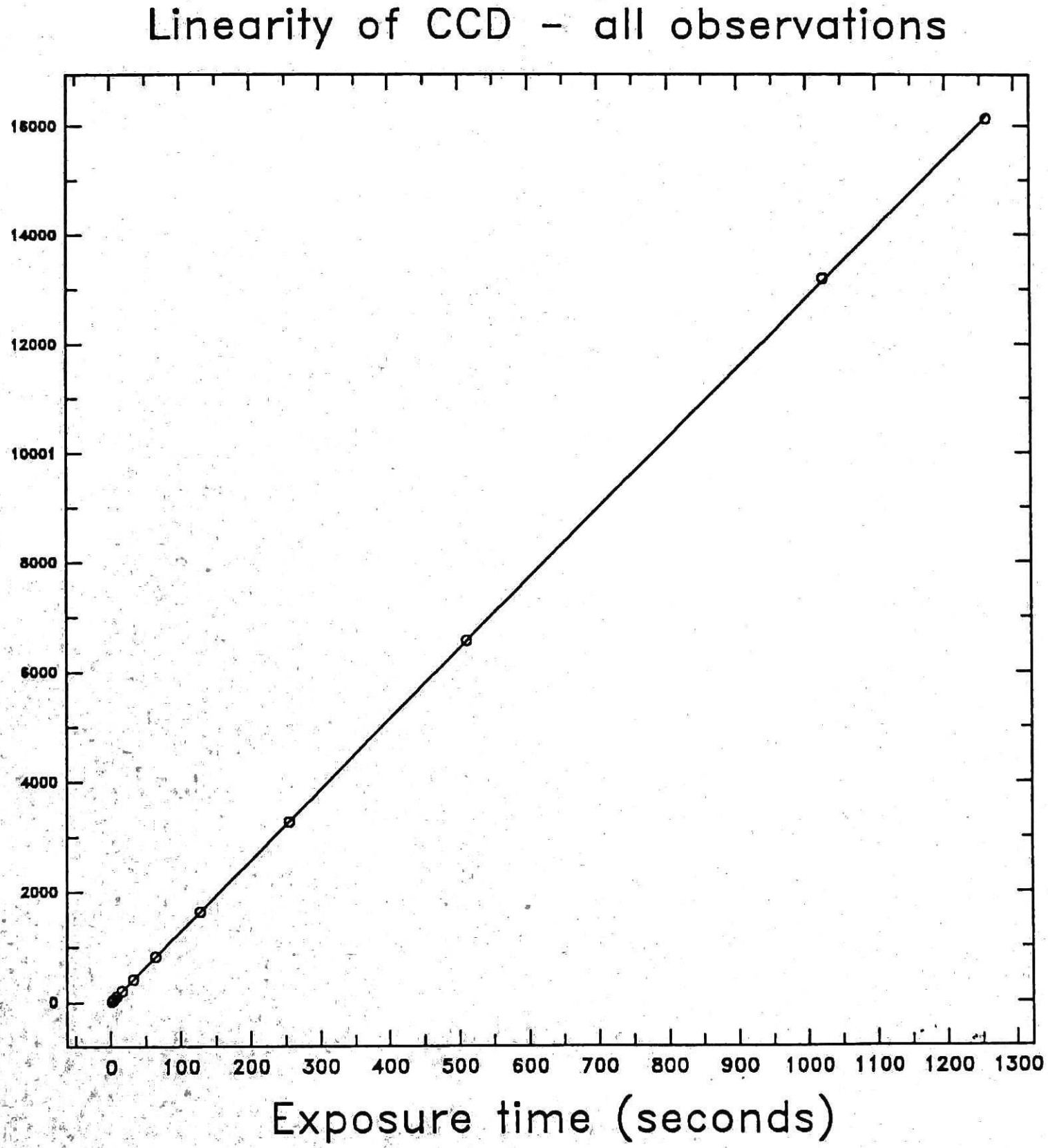

Stability of light source reference counts
counts
129.0
128.8
128.6
128.4
128.2
128.0
127.8
127.6
127.4
127.2
127.0
126.8
126.6
126.4
126.2
-.5
0
.5
1.0
1.5
2.0
2.5
3.0
3.5
log(exposure time)

Figure 2



PHYS159

Figure 3

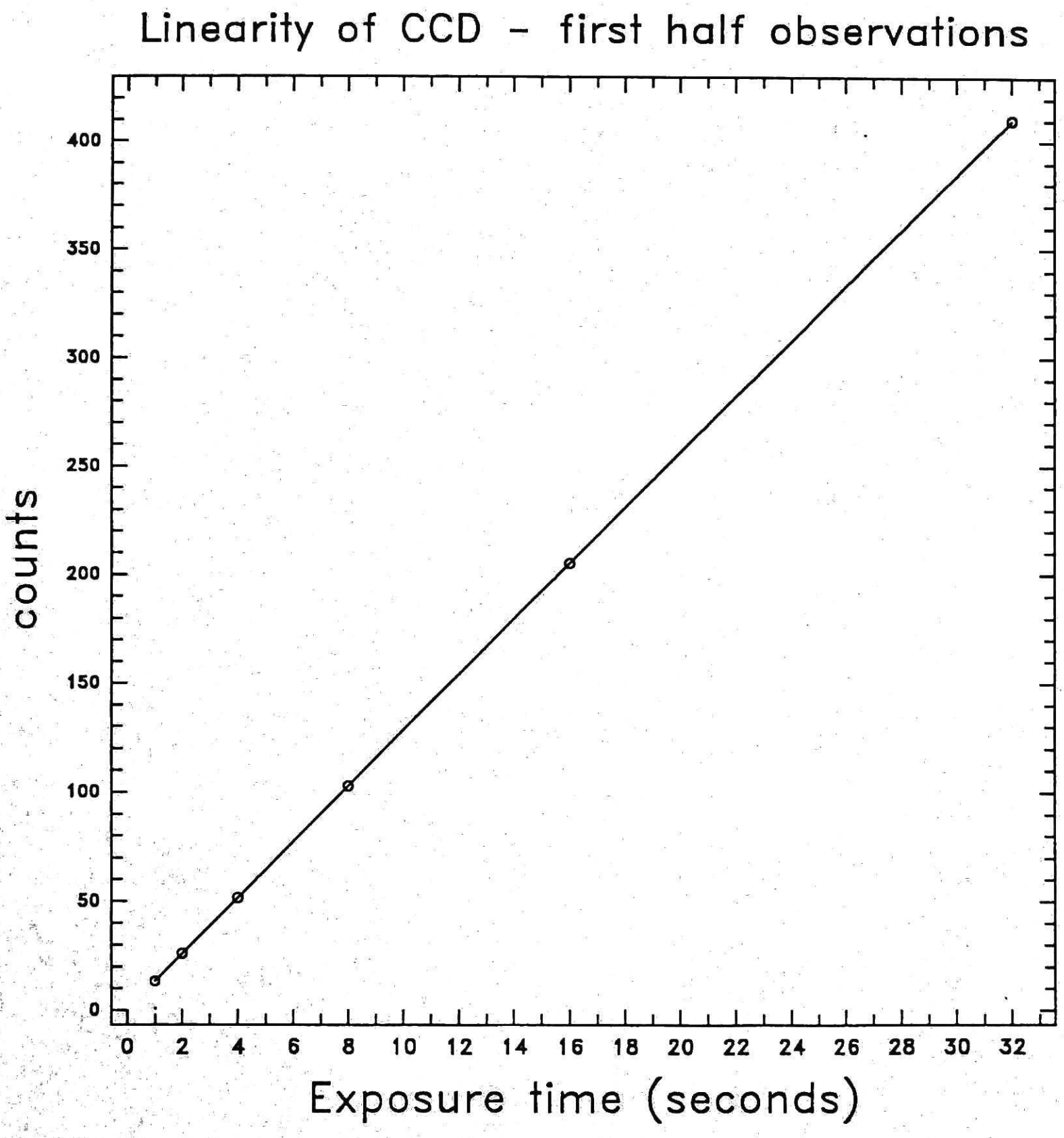

Linearity of CCD - first half observations
counts
0
50
100
150
200
250
300
350
400
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
Exposure time (seconds)

Figure 4

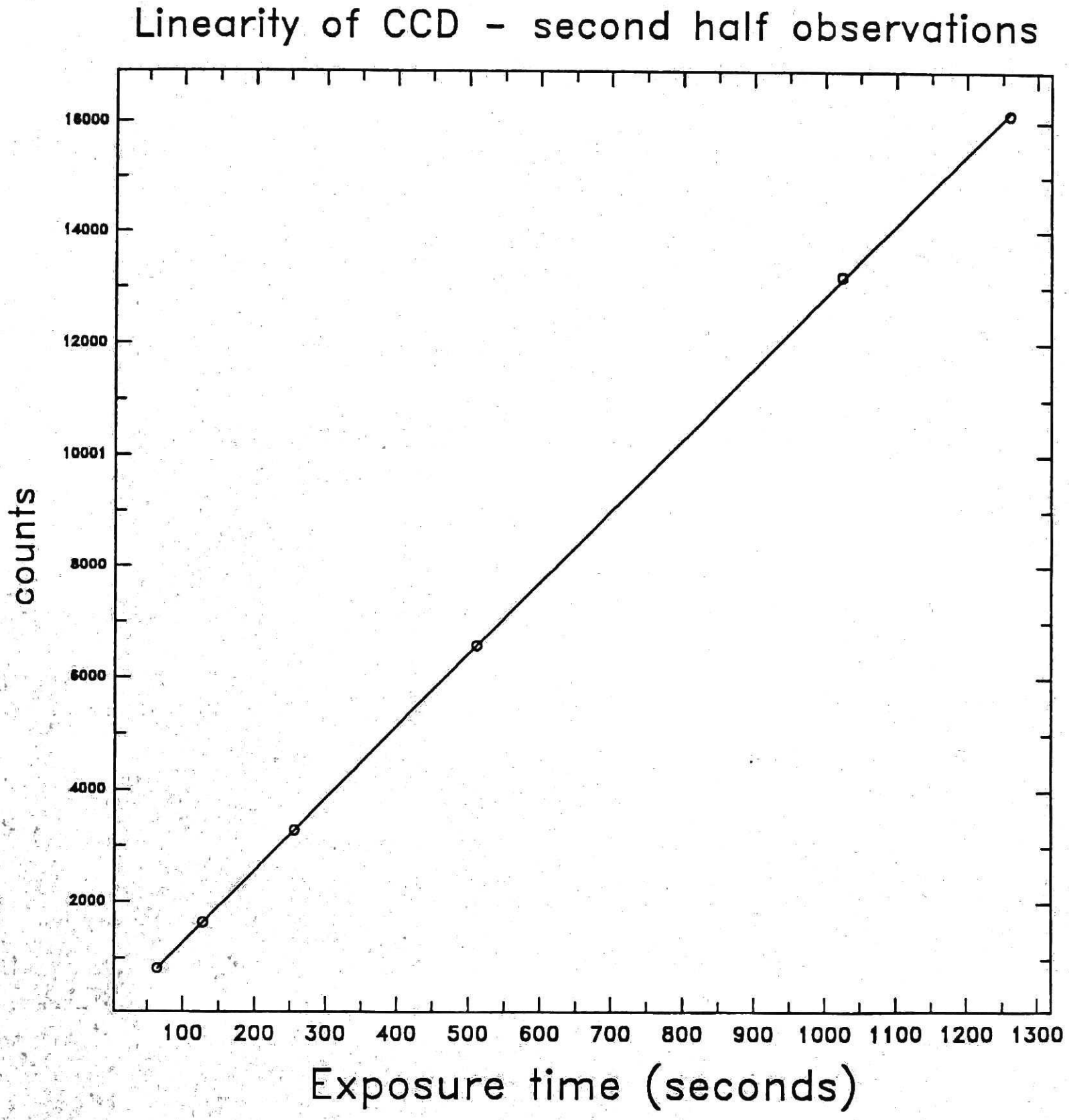
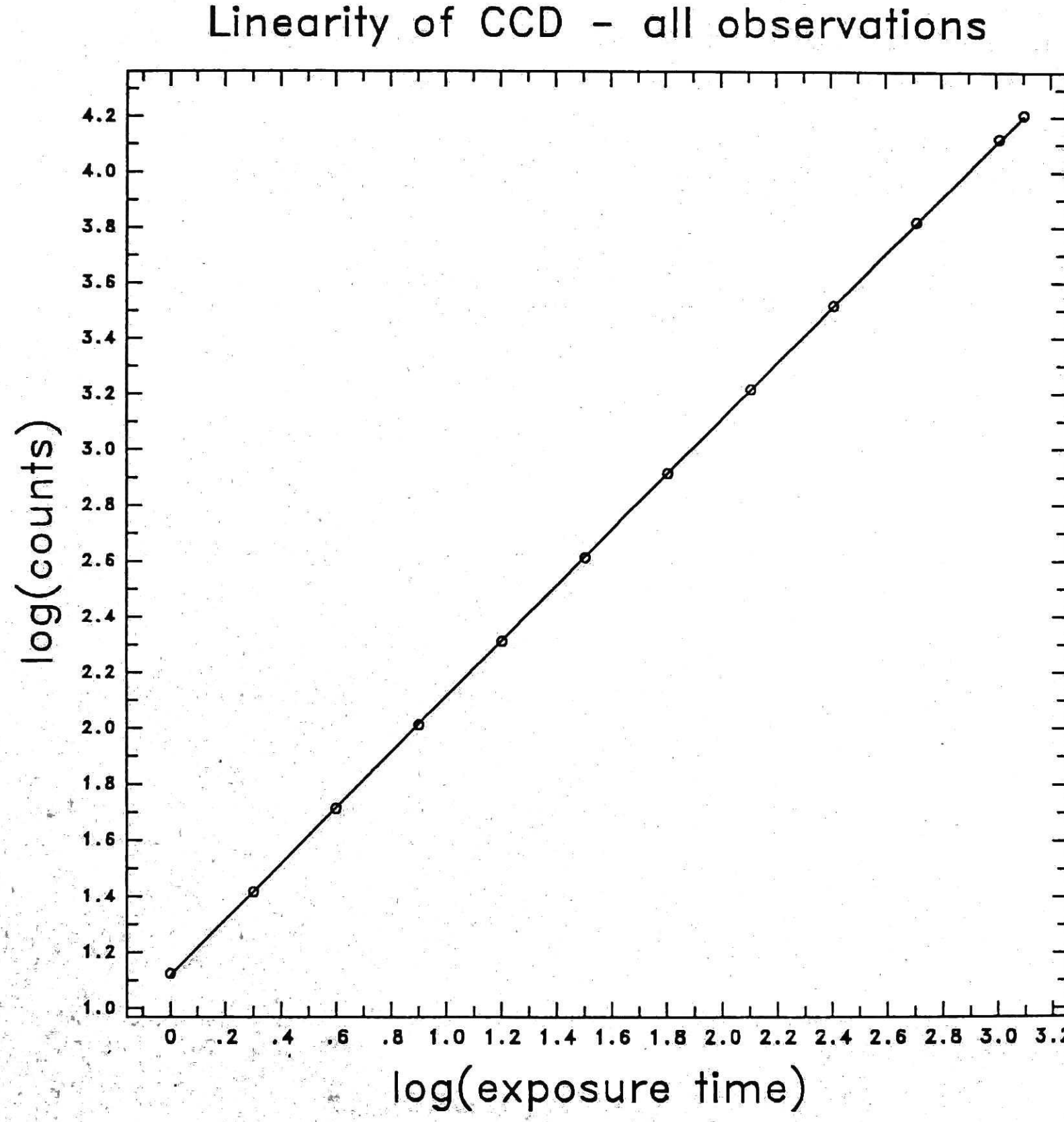

Linearity of CCD - second half observations
counts
16000
14000
12000
10001
8000
6000
4000
2000
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
Exposure time (seconds)

Figure 5

Figure 5



University of Canterbury Department of Physics & Astronomy

Mt John University Observatory

Mt John Photometrics CCD System

Use and Performance Note
Number 3

EVALUATION OF THE SPECTRAL RESPONSE FOR VARIOUS OPERATING TEMPERATURES OF THE MT JOHN CCD

K. Pollard

1989 September

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Evaluation of the spectral response for various operating temperatures of the Mt John CCD

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New Zealand.

September 1989

1 Introduction

When a CCD chip is exposed to light, photons that penetrate the silicon lattice of the CCD produce electron hole pairs. The electrons accumulate in the potential wells of the CCD until readout. Thermal electrons in the silicon lattice produce free electrons that are indistinguishable from electons produced by photons. The contribution of thermally-generated charge, called dark current, is reduced by cooling the CCD. The aim of the procedure reported here is to investigate the sensitivity of the MJUO TH7882 CDA chip over a range of temperatures and wavelengths to determine the optimum operating temperature.

2 Experimental procedure

2.1 CCD Temperature Control

A temperature control dial and digital readout on the frontplate of the camera (CE200) electronics unit allows the observer to adjust and optimize the CCD temperature. Temperature regulation begins when AC + DC is applied to the CE200. If the CE200 is disconnected from power and connected to the camera head, then the CCD is cooled to its maximum cold temperature (which will depend on the ambient temperature also). The temperature control dial has a range of 100°C and is nominally calibrated to cover a range from -50 to -150°C. The dial is graduated from 0 to 1000 with 1000 representing approximately -150°C. The CCD should be operated at the highest temperature which yields acceptable dark current. The manufacturer suggests a highest operating temperature of -90 degrees C and a lowest operating temperature of -130°C due to the fact that long wavelength quantum efficiency and performance deteriorate with a decrease in temperature.

2.2 Stable light source

The stable light source consists of a control box and a 'top hat' which contains an arrangement of different coloured LEDs that illuminate the depolished crown of the hat. The arrangement consists of infra-red, red, blue and green LEDs. Only one set of LEDs can be selected at any one time. The LEDs are powered by a controlled stablized power supply. By altering the current

into the LEDs the intensity can be varied. The current is set by a coarse and a fine adjustment. There are six LEDs of each colour (except for blue where there are only two) mounted in a circular pattern behind a depolished window in the top hat. The brightness of the LEDs were set at:

- red (655 nm) coarse = high, fine = 3.0 on outer scale
- green (555 nm) coarse = high, fine = 10.0 on outer scale
- infra-red (830 nm) coarse = low, fine = 5.0 on outer scale
- blue (480 nm) coarse = high, fine = 10.0 on outer scale

The LEDs were turned on and left for several hours to stabilize before use. The light source LEDs were assumed to have negligible drift. The top hat, CCD dewar and electronics unit were set up in the Physics 521A curtained darkroom. The Photometrics 3000 computer and the observer were in the non-curtained part of the darkroom.

2.3 CCD camera

The camera head was mounted on an optical bench at a distance of about 0.5 meters from the stable light source. A 50mm Pentax camera lens was then attached to the camera head and focussed.

3 Observations

An observation is initiated by typing: clrims 100 obs , where 100 is the duration of the exposure in deciseconds. The obs command closes the shutter, clears the CCD array twice, opens the shutter for the specified time and reads the CCD out. For temperatures hotter than -90°C each set of timed observations of the stable light source by the CCD consisted of:

- a 10 second dark exposure
- a 10 second observation
- another 10 second dark exposure

For cooler temperatures, only one dark exposure was made. The dark frame contained the standard bias component as well as the dark signal. For the room temperature observations a 2 second exposure was taken which was scaled later (to avoid saturation of the CCD chip). The dark frames and observations were saved on mini data cassette tape for later analysis.

4 Image Analysis

The images were analysed using the PM3000 `video` terminal. The full frame image was displayed with intensity varying linearly between two selected values of minimum and maximum. A reasonably constant-intensity region of the stable light source was chosen in each case. The FORTH commands available in the software allowed a 50×50 pixel box to be displayed at the chosen region of the light source ('sb' and 'pcur') together with information about the intensity inside the box. The 'stats' command gave values of maximum, minimum and mean intensity and the rms of the mean intensity over the 2500 pixels. Thus in this way an average was obtained over the same region of the constant light source for differing temperatures.

5 Results

Table 1 shows the operating temperature, counts obtained and scaled counts for each set of LEDs and the dark images. Graphs of temperature *vs.* counts were plotted for each LED colour (see Figures 1 to 4). A composite graph was also plotted with all counts scaled to the red LED counts at -145°C (Figure 5). A graph for the dark current was obtained by analysing the same area of the CCD on the dark images associated with the red LEDs (Figure 6).

Table 1 : Temperature Dependence of CCD Sensitivity at Various Wavelengths

Temperature(°C)	Red (655 nm) LEDs Counts (per 10 seconds)	Dark Current
23.45	5705.432	34152.825
-0.15	5864.400	1825.600
-15.05	5864.875	619.352
-31.55	5947.905	350.051
-46.80	6017.623	317.451
-59.85	6058.705	315.066
-75.00	6075.996	314.790
-90.10	6086.497	315.037
-105.30	6043.949	315.283
-120.25	6012.524	315.532
-135.10	5949.689	315.921
-140.05	5921.004	316.130
-145.00	5888.652	316.670
Temperature(°C)	Green (555 nm) LEDs Counts (per 10 seconds)	Counts (scaled)
22.40	1513.972	4961.376
-1.60	1619.785	5019.278
-16.20	1693.202	5246.778
-30.65	1729.194	5358.307
-46.70	1766.656	5474.392
-61.80	1803.498	5588.555
-76.50	1820.060	5639.877
-90.40	1847.234	5724.082
-105.30	1873.690	5806.062
-120.30	1893.573	5867.674
-135.10	1902.830	5896.359
-140.00	1903.174	5897.425
-144.95	1900.343	5888.652

Table 1 (cont.) : Temperature Dependence of CCD Sensitivity at Various Wavelengths

Temperature(°C)	Infra red (830 nm) LEDs Counts (per 10 seconds)	Counts (scaled)
23.20	3639.860	8984.521
-0.85	3445.528	8504.838
-17.40	3361.141	8296.540
-32.25	3260.637	8048.458
-46.90	3154.662	7786.873
-61.60	3036.809	7495.968
-76.20	2977.689	7350.038
-90.10	2862.721	7066.255
-105.00	2730.719	6740.425
-121.85	2600.853	6419.867
-136.15	2471.743	6101.174
-140.75	2429.541	5997.006
-145.05	2385.644	5888.652
Temperature(°C)	Blue (480 nm) LEDs Counts (per 10 seconds)	Counts (scaled)
23.80	302.550	3796.325
-2.65	326.296	4094.284
-17.00	386.616	4851.165
-32.25	403.986	5069.120
-47.50	418.290	5248.603
-61.50	428.980	5382.739
-76.20	434.915	5457.210
-90.35	444.626	5579.061
-105.30	454.592	5704.112
-120.15	462.582	5804.369
-135.05	467.502	5866.104
-140.00	468.766	5881.964
-144.75	469.299	5888.652

The CCD sensitivity at 480 nm (blue LEDs) increased monotonically with decreasing temperature. At 555 nm (green LEDs) and 655nm (red LEDs) a peak in sensitivity occurred at approximately -138°C and -105°C respectively. The sensitivity at 830 nm (infra-red LEDs)

decreased monotonically with decreasing temperature. The variation in CCD sensitivity with temperature can be described by a percentage defined by:

$$\frac{maximum - minimumcounts}{averagecounts} \times 100\%$$

The percentage variation in CCD sensitivity for each set of LEDs is:

- 6.4% at 655 nm (red LEDs)
- 21.8% at 555 nm (green LEDs)
- 42.5% at 830 nm (infra-red LEDs)
- 39.6% at 480 nm (blue LEDs)

As seen in Figure 6, the dark current is reduced to the DC offset at approximately -50°C and counts merely fluctuate about this value for temperatures cooler than -50°C.

6 Conclusions

The optimum operating temperature depends on the CCD sensitivity at that spectral range and on the length of the exposure (since this determines the accumulated dark current). The dark current analysis of the ten second exposures obtained, seem to indicate that -50°C would be the highest temperature the CCD could be used at. (Also the CCD temperature control doesn't actually allow higher operating temperatures to be selected.) An operating temperature lower than approximately -110°C is unsuitable since this temperature cannot be held constant when the telescope position is changed.

Figure 2

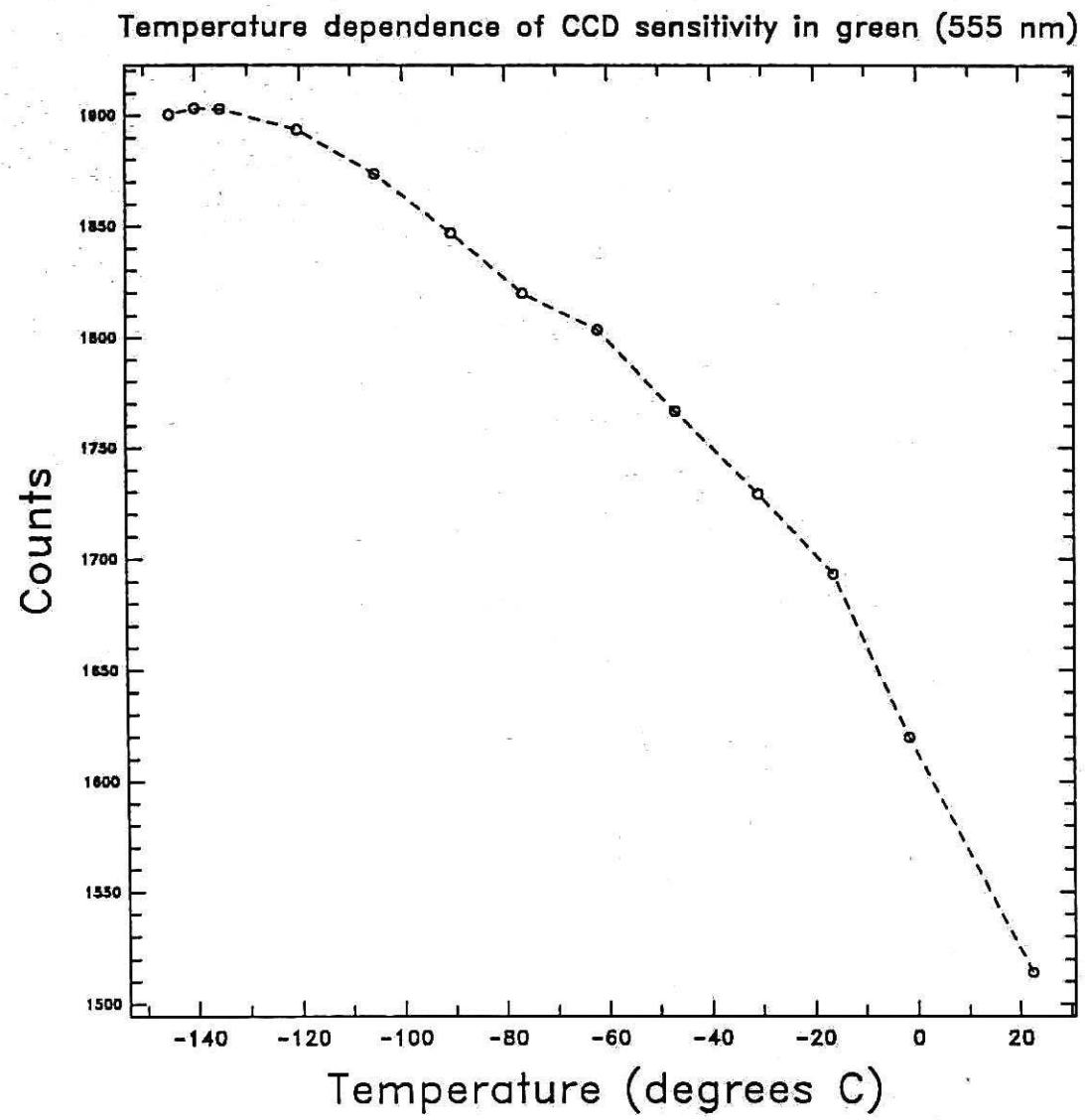


Figure 1

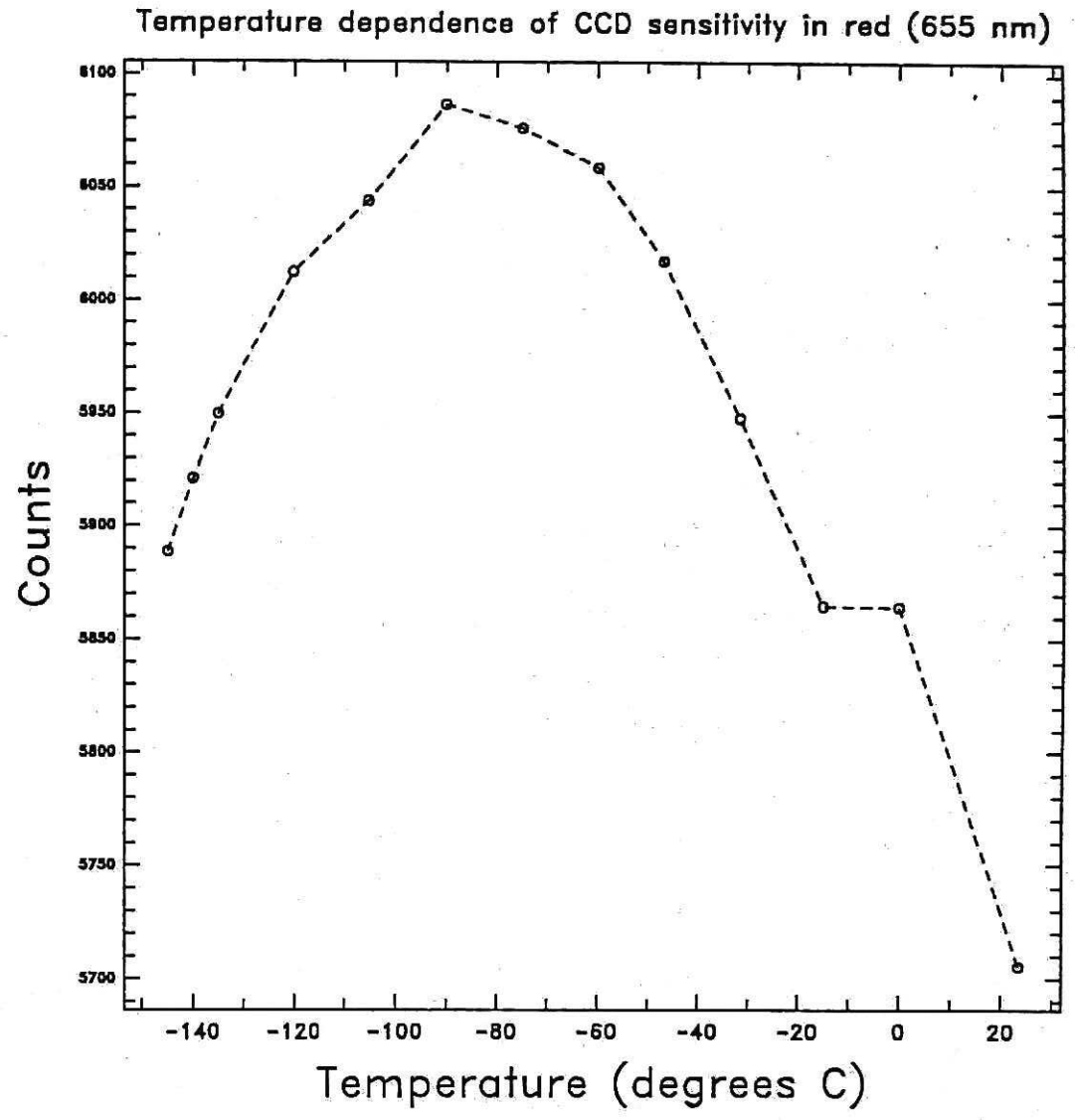


Figure 3

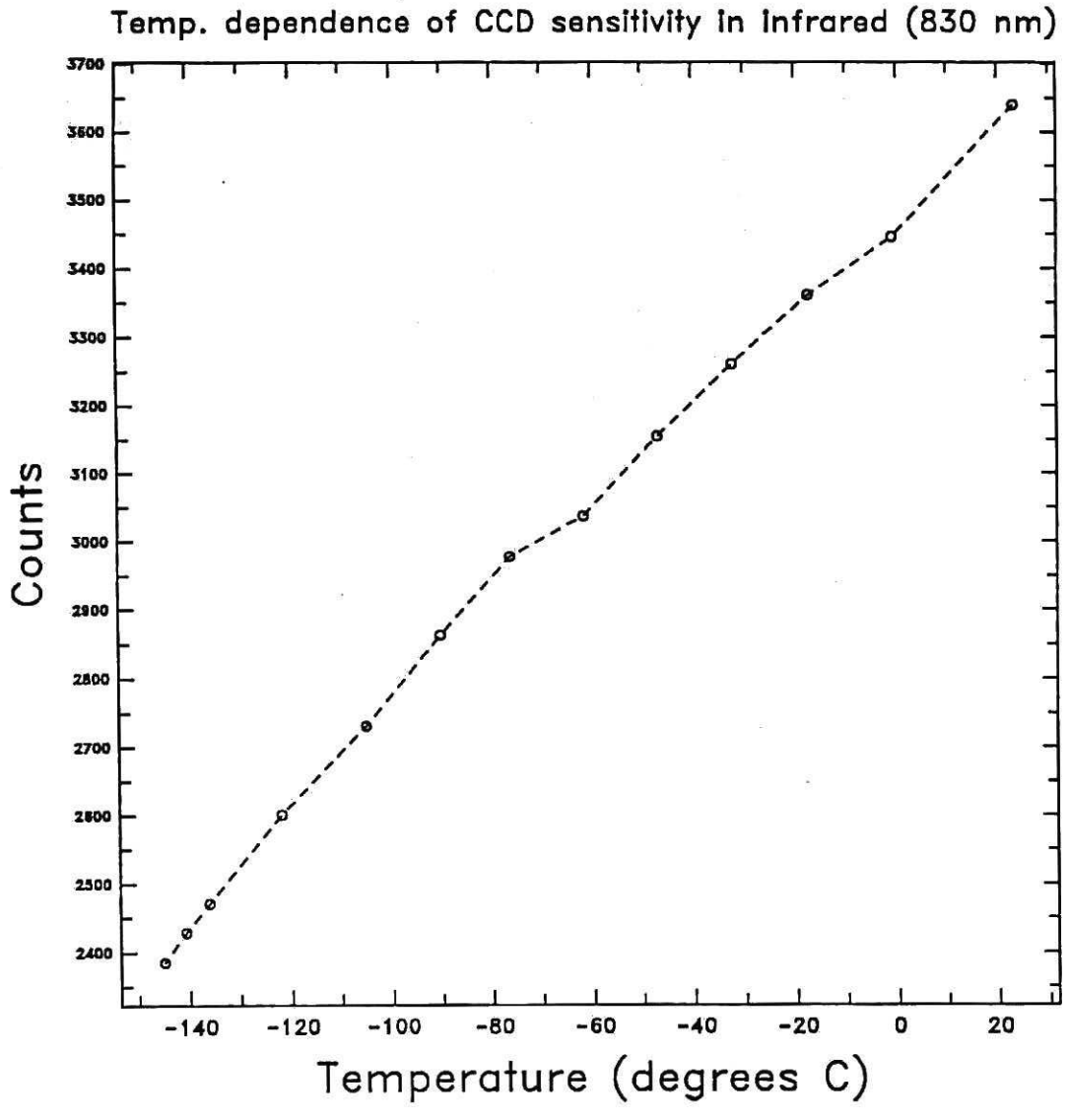


Figure 4

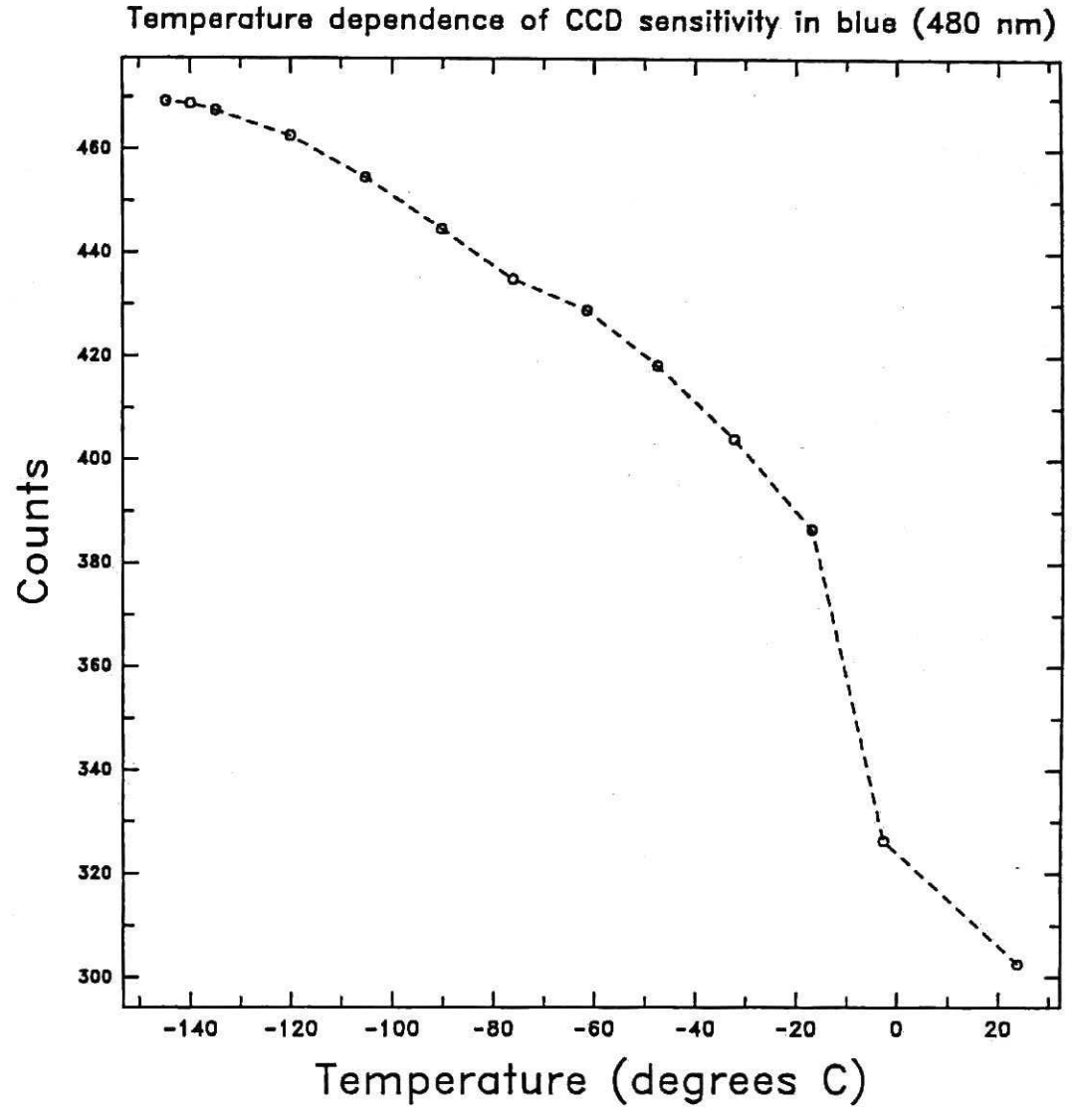


Figure 5

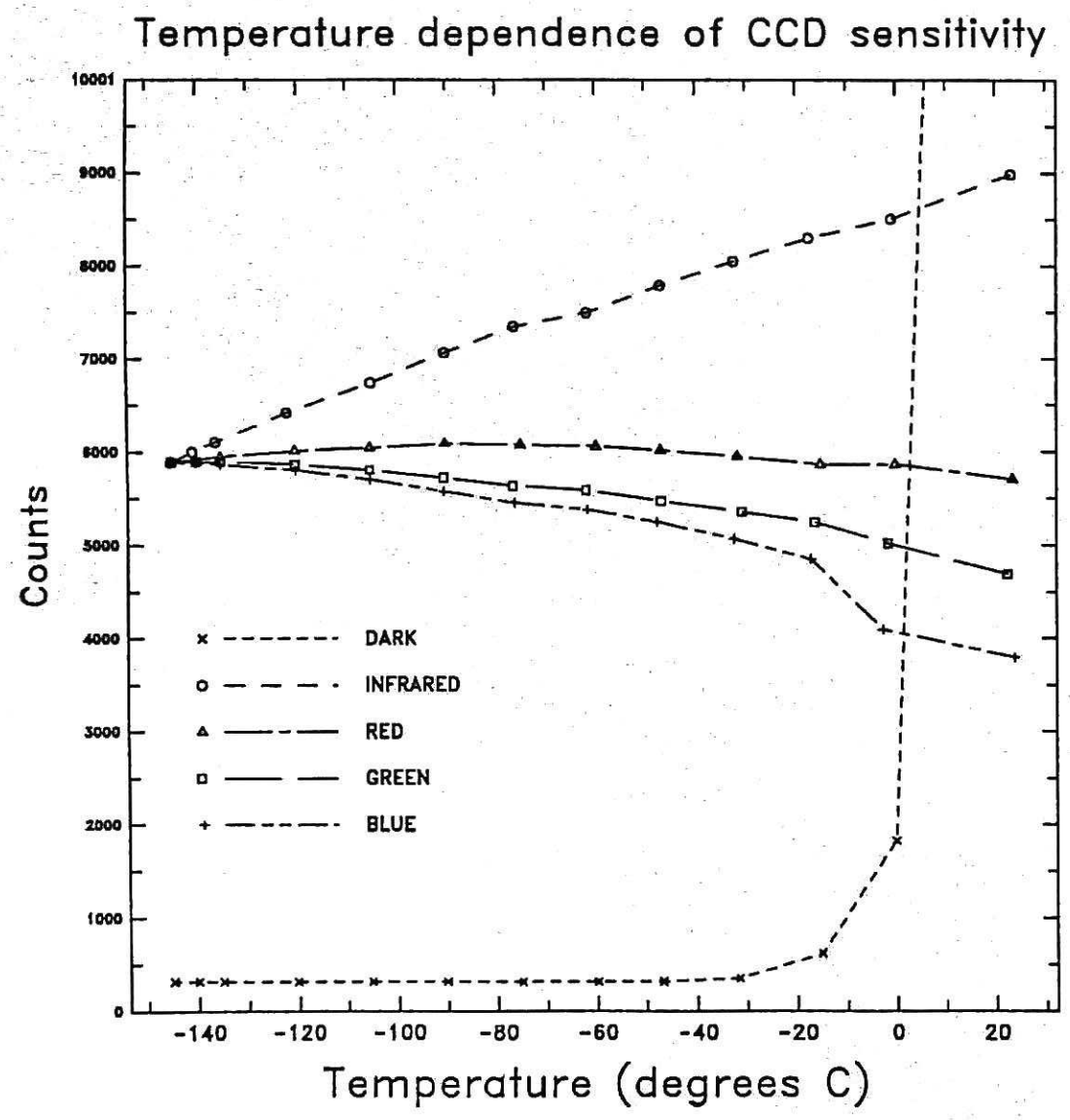
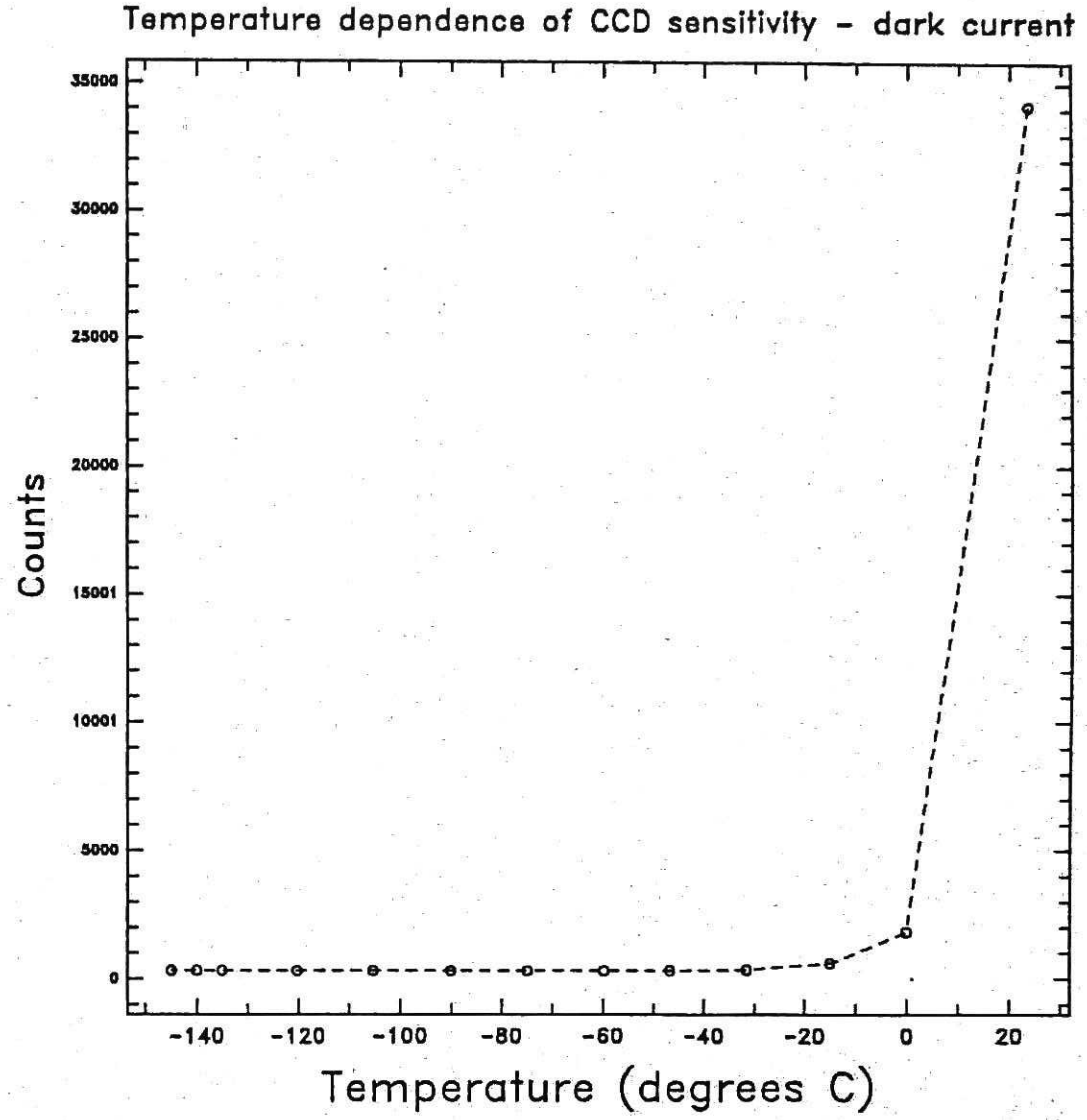


Figure 6



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Mt John University Observatory

Mt John Photometrics CCD System

Use and Performance Note
Number 4

FLEXURE TESTS OF THE MT JOHN BOLLER & CHIVENS SPECTROGRAPH AS TEMPORARILY MODIFIED WITH A TELEPHOTO CAMERA LENSS FOR USE WITH THE PHOTOMETRICS CCD DETECTOR SYSTEM

R.Hughtenburg & W.Tobin

1990 December 14

These Notes are intended for guidance only: individual observers have the sole responsible for the integrity of their own data. Users of the CCD system are encouraged to summarize the performance that they obtain in a Note in this series. Contact Dr. W. Tobin to be allocated a series number.

FLEXURE TESTS OF THE MT JOHN BOLLER & CHIVENS SPECTROGRAPH AS TEMPORARILY MODIFIED WITH A TELEPHOTO CAMERA LENS FOR USE WITH THE PHOTOMETRICS CCD DETECTOR SYSTEM

Authors : R. Hugtenburg and W. Tobin
Date : 1990 December 14

These tests were made in December 1990 with the B & C spectrograph mounted on the 1-metre McLellan Telescope at MJUO. The spectrograph was mounted with the eyepiece lens to the south. The spectrograph Maksutov camera had been replaced with a telephoto lens of focal length ~ 200 mm so that the CCD could be used as the detector.

Tests of flexure were made by recording helium-argon wavelength calibration spectra at different orientations of the telescope and determining how much the positions of the emission lines varied.

The 300 line mm^{-1} grating was used set at -13°20′. The 56 μm slit (mapping to 0.70 pixels) was selected, and a Corning 3-71 filter separated out the second diffraction order. The CCD dewar was mounted against shims in order to produce a better focus. With these settings, the wavelength range spanned by the 576 pixels of the CCD's length was approximately 630-720 nm.

Arc spectra were obtained, by Dr W. Tobin, at a variety of hour angle settings and declinations, and with the telescope over and under the pole, as appropriate. An 80 x 576 pixel area of the CCD was read out. These spectra were converted to wavelength calibrations in Christchurch by R. Hugtenburg using the following sequence of MIDAS commands:

ROTATE/COUNTER arcframe rotatedarcframe

(rotate the frame so that the dispersion is approximately parallel to the MIDAS x axis.

N.B. : Resulting pixel positions are negative.)

AVERAGE/ROW summedframe = rotatedarcframe 30, 40 NO

(sum over 10 rows to create a 1-dimensional frame)

$COPY MID_ARC: HEAR.TBL *

(copy MIDAS-supplied helium-argon wavelength table into work directory)

SEARCH/LINE summedframe 4,20

(automatic feature detection, using default parameters LINE GRAVITY EMISSION)

PLOT/IMAGE summedframe

(put summed spectrum on Tektronix emulator - i.e. second terminal or GPX window)

IDENTIFY/LINE

(a few lines are then interactively identified using the Tektronix screen cursor)

CALIBRATE/LINE 4,3 ? HEAR

(MIDAS determines wavelengths for lines found by SEARCH and determines an interpolating 3rd order polynomial. The polynomial is put in the keyword DISPCOE.)

READ/KEY DISPCOE

(Displays the polynomial. The form is

pixel no. = DISPCOE(1) + DISPCOE(2)*λ

+ DISPCOE(3)*λ^2 + DISPCOE(4)*λ^3.)

The results of these reductions are given in the attached table, where zeroth = DISPCOE(1), etc. In the table results are given in the order in which the arc spectra were acquired. Calculated pixel positions for wavelengths at various locations on the CCD are also given in the table, and selectively plotted in the attached Figures. The figures all plot pixel positions for 670 nm (midway along the CCD).

Shifts at the ends of the CCD are the same to within ~ 0.1 pixel, and have not been plotted here.

Figure 1 plots pixel shifts at the South Celestial Pole. The branch of points marked 'a' indicates the pixel shifts as the telescope was moved eastwards (negative) in hour angle from an HA = 0h position where the telescope mirror cell was to the west of the polar axis. Thus for these points the telescope mirror cell was above the polar axis. The telescope was then returned to HA = 0 with the mirror cell west of the polar axis, and westward (positive) hour angles were explored (branch b). The two HA = 0 points show that there is a hysteresis-like effect in the equipment: thus return to a previous pointing does not necessarily return the wavelengths to their previous positions on the CCD chip.

Figures 2 and 3 present analogous information for declination 61° south and for the equator.

Figure 4 shows meridian points for the telescope at HA = 0h with the mirror to the west of the polar axis. It can be seen that there are both flexure - and hysteresis-like components in the wavelength shifts.

Figure 5 plots the data of figures 1-4 in a single graph. It can be seen that shifts can occur of up to 1 pixel (≡ 0.16 nm of wavelength, or 72 kms^{-1} of radial velocity). Observers are recommended to acquire helium-argon wavelength arcs with sufficient frequency to avoid any significant wavelength calibration shift.

The maximum shift of 1 pixel is relatively small, but the reader is cautioned that earlier tests of the Boller & Chivens spectrograph and CCD on the Mt John Boller & Chivens telescope resulted in shifts some 14 times greater. For these earlier tests it is possible that the dewar was not completely tightly bolted against the shims, or that the grating was not locked; and for these reasons this earlier set of tests is considered less reliable. However, the user is warned that there is the possibility that greater flexure effects may occur than reported here.

TABLE 1 : Dispersion coefficients and resulting pixel positions for 630, 670 and 710 nm.

Table : t208dispcoe

Sequence	dec	H_Angle	ang_re	Zeroth	First	Second	Third	W_6300	W_6700	W_7100
1	-44.0	Zenith	0.0	-8645.4003	2.5498105	-2.9926225e-04	1.5566770e-08	-566.889	-313.644	-56.038
2	-90.0	0.00hr	0.0	-8422.8128	2.4505673	-2.8452623e-04	1.4838260e-08	-566.823	-313.595	-55.976
3	-90.0	-1.30hr abv	-22.5	-8351.0005	2.4204404	-2.8033960e-04	1.4645944e-08	-566.730	-313.536	-55.848
4	-90.0	-3.00hr abv	-45.0	-8314.6817	2.4060623	-2.7846823e-04	1.4566150e-08	-566.671	-313.544	-55.838
5	-90.0	-4.30hr abv	-67.5	-8594.5288	2.5282872	-2.9625159e-04	1.5428054e-08	-566.806	-313.551	-55.862
6	-90.0	-6.00hr abv	-90.0	-8254.1235	2.3774487	-2.7397845e-04	1.4332024e-08	-566.722	-313.567	-55.902
7	-90.0	-7.30hr abv	-112.5	-8378.7504	2.4318699	-2.8189503e-04	1.4715597e-08	-566.793	-313.583	-55.929
8	-90.0	-9.00hr abv	-135.0	-8418.9554	2.4475445	-2.8389567e-04	1.4798636e-08	-566.890	-313.602	-55.976
9	-90.0	-10.30hr abv	-157.5	-8530.9127	2.4972465	-2.9124202e-04	1.5160069e-08	-566.926	-313.628	-56.017
10	-90.0	-12.00hr	-180.0	-8586.0998	2.5214117	-2.9476559e-04	1.5331020e-08	-566.977	-313.665	-56.069
11	-90.0	0.00hr	0.0	-8544.3561	2.5097750	-2.9405529e-04	1.5346179e-08	-566.562	-313.443	-55.714
12	-90.0	+1.30hr blw	22.5	-8145.6185	2.3308954	-2.6732618e-04	1.4015731e-08	-566.562	-313.478	-55.790
13	-90.0	+3.00hr blw	45.0	-8358.2400	2.4241201	-2.8093885e-04	1.4677511e-08	-566.679	-313.528	-55.872
14	-90.0	+4.30hr blw	67.5	-8589.5483	2.5243376	-2.9539327e-04	1.5371169e-08	-566.866	-313.611	-56.016
15	-90.0	+6.00hr blw	90.0	-8825.6233	2.6280163	-3.1056871e-04	1.6110929e-08	-567.103	-313.772	-56.198
16	-90.0	+7.30hr blw	112.5	-8697.2159	2.5725610	-3.0261557e-04	1.5731675e-08	-567.235	-313.964	-56.344
17	-90.0	+9.00hr blw	135.0	-8591.0123	2.5264849	-2.9597295e-04	1.5413212e-08	-567.296	-314.065	-56.408
18	-90.0	+10.30hr blw	157.5	-8776.9058	2.6102949	-3.0855882e-04	1.6042609e-08	-567.341	-314.112	-56.436
19	-90.0	+12.00hr	180.0	-8343.8664	2.4169282	-2.7980111e-04	1.4618068e-08	-567.321	-314.145	-56.483
20	-61.0	0.00hr abv	0.0	-8523.0270	2.4935735	-2.9067591e-04	1.5130971e-08	-566.987	-313.690	-56.087
21	-61.0	-1.30hr abv	-22.5	-8466.6823	2.4686583	-2.8700325e-04	1.4950595e-08	-566.943	-313.662	-56.060
22	-61.0	-3.00hr abv	-45.0	-8713.1915	2.5782591	-3.0322725e-04	1.5750260e-08	-566.943	-313.631	-56.046
23	-61.0	-4.30hr abv	-67.5	-8828.8199	2.6288656	-3.1060676e-04	1.6108745e-08	-567.006	-313.644	-56.064
24	-61.0	-6.00hr E	-90.0	-8567.2959	2.5129265	-2.9349195e-04	1.5267332e-08	-567.004	-313.694	-56.101
25	-61.0	-7.30hr blw	-112.5	-8752.9061	2.5954361	-3.0571923e-04	1.5871170e-08	-567.116	-313.760	-56.150
26	-61.0	-9.00hr blw	-135.0	-8484.4717	2.4753498	-2.8783462e-04	1.4984282e-08	-567.149	-313.806	-56.192
27	-61.0	-9.00hr abv	-135.0	-8527.0097	2.4957996	-2.9106423e-04	1.5152766e-08	-566.908	-313.634	-56.039
28	-61.0	-7.30hr abv	-112.5	-8282.0745	2.3863986	-2.7480147e-04	1.4348172e-08	-566.916	-313.643	-56.018
29	-61.0	-6.00hr W	-90.0	-8502.0849	2.4854660	-2.8965092e-04	1.5089169e-08	-566.893	-313.629	-56.000
30	-61.0	-4.30hr blw	-67.5	-8413.6948	2.4488376	-2.8460617e-04	1.4858483e-08	-566.718	-313.572	-55.930
31	-61.0	-3.00hr blw	-45.0	-8438.6803	2.4585713	-2.8585158e-04	1.4910645e-08	-566.768	-313.560	-55.918
32	-61.0	0.00hr abv	0.0	-8301.2864	2.3982005	-2.7702523e-04	1.4481553e-08	-566.685	-313.490	-55.797
33	-61.0	+1.30hr abv	22.5	-8349.4494	2.4215983	-2.8078240e-04	1.4681054e-08	-566.680	-313.545	-55.832
34	-61.0	+3.00hr abv	45.0	-8496.2373	2.4814453	-2.8884574e-04	1.5038933e-08	-566.979	-313.684	-56.090
35	-61.0	+4.30hr abv	67.5	-8580.7930	2.5189726	-2.9440813e-04	1.5313647e-08	-567.193	-313.879	-56.278
36	-61.0	+6.00hr W	90.0	-8715.5957	2.5820422	-3.0421720e-04	1.5820321e-08	-567.287	-314.056	-56.418
37	-61.0	+7.30hr blw	112.5	-8773.9028	2.6089982	-3.0836587e-04	1.6032555e-08	-567.364	-314.160	-56.512
38	-61.0	+9.00hr blw	135.0	-8580.4847	2.5242176	-2.9599596e-04	1.5431585e-08	-567.372	-314.236	-56.562
39	-61.0	+10.30hr blw	157.5	-8625.1807	2.5439529	-2.9890099e-04	1.5574013e-08	-567.422	-314.275	-56.603
40	-61.0	+12.00hr blw	180.0	-8535.9694	2.5044328	-2.9307959e-04	1.5288691e-08	-567.481	-314.340	-56.648
41	-44.0	Zenith	0.0	-8631.4061	2.5439289	-2.9847749e-04	1.5532935e-08	-567.262	-314.005	-56.353
42	0.0	0.00hr W	0.0	-8825.7885	2.6323568	-3.1187533e-04	1.6208607e-08	-567.359	-314.132	-56.452
43	0.0	-2.00hr abv	-30.0	-8649.2080	2.5530897	-3.0001997e-04	1.5617898e-08	-567.327	-314.118	-56.461
44	0.0	-4.00hr abv	-60.0	-8676.8138	2.5652933	-3.0181433e-04	1.5705602e-08	-567.338	-314.130	-56.484
45	0.0	0.00hr W	0.0	-8354.7625	2.4203317	-2.8009131e-04	1.4622134e-08	-567.276	-314.042	-56.388
46	0.0	+2.00hr blw	30.0	-8654.4534	2.5556003	-3.0042047e-04	1.5639259e-08	-567.310	-314.096	-56.425
47	0.0	+4.00hr blw	60.0	-8722.1070	2.5864428	-3.0510100e-04	1.5875356e-08	-567.391	-314.205	-56.540
48	-44.0	Zenith	0.0	-8788.7844	2.6130986	-3.0858923e-04	1.6024740e-08	-567.232	-313.946	-56.337

FIGURE 1 : Flexure tests at the South Celestial Pole. Arrows indicate order in which the tests were performed.

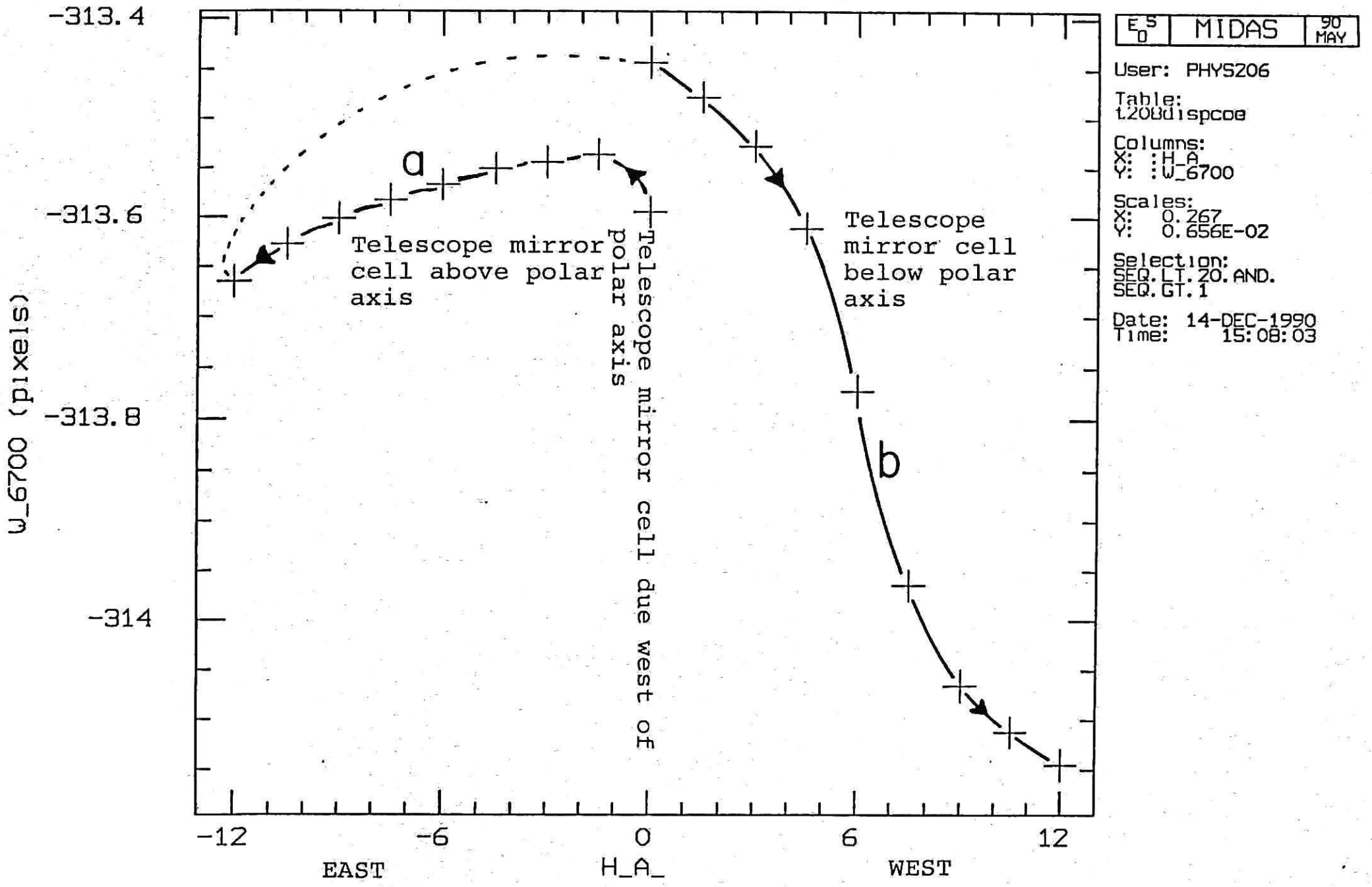


FIGURE 2 : Flexure tests for declination 61° South

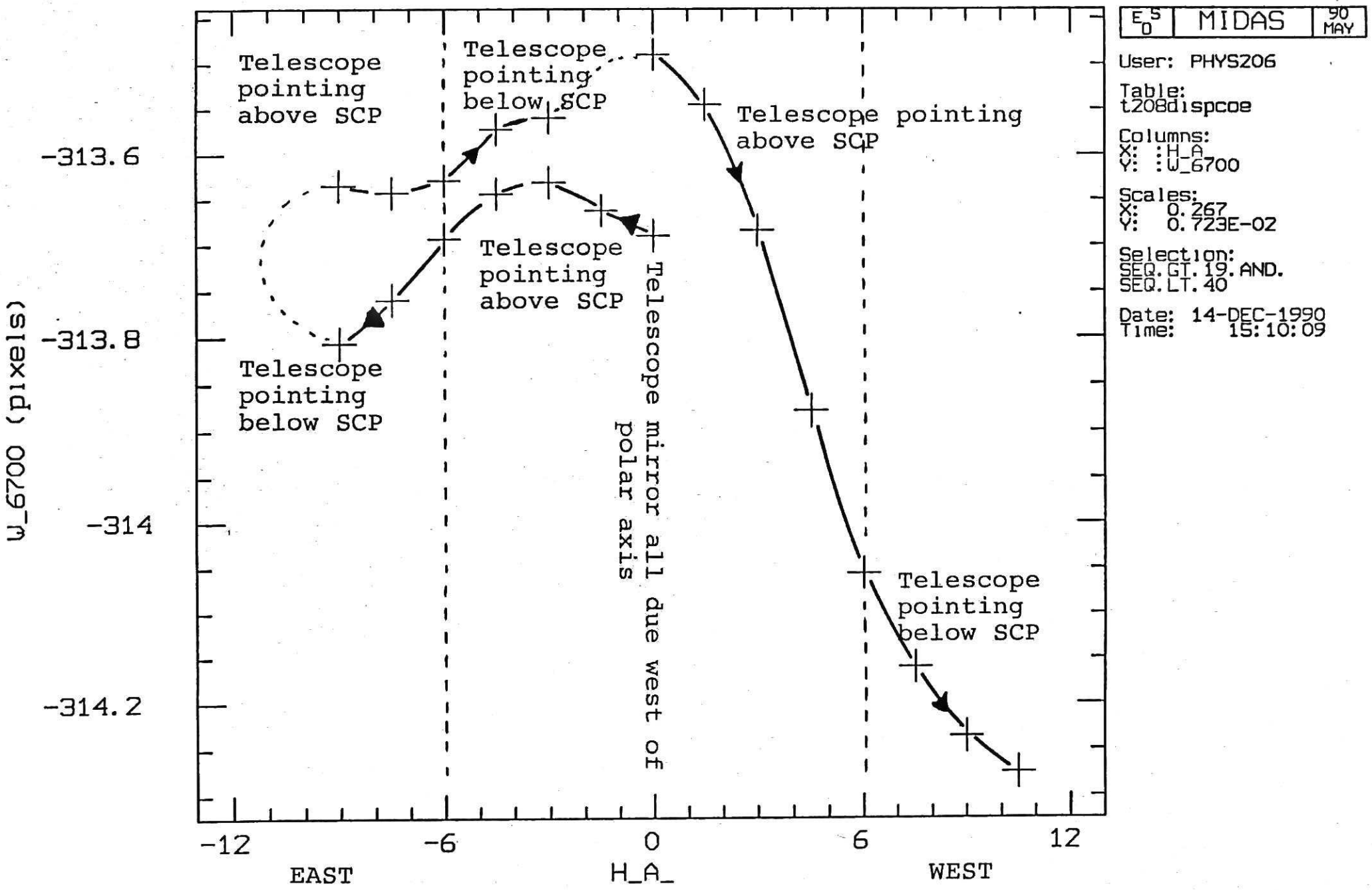


FIGURE 3 : Flexure tests for the Equator

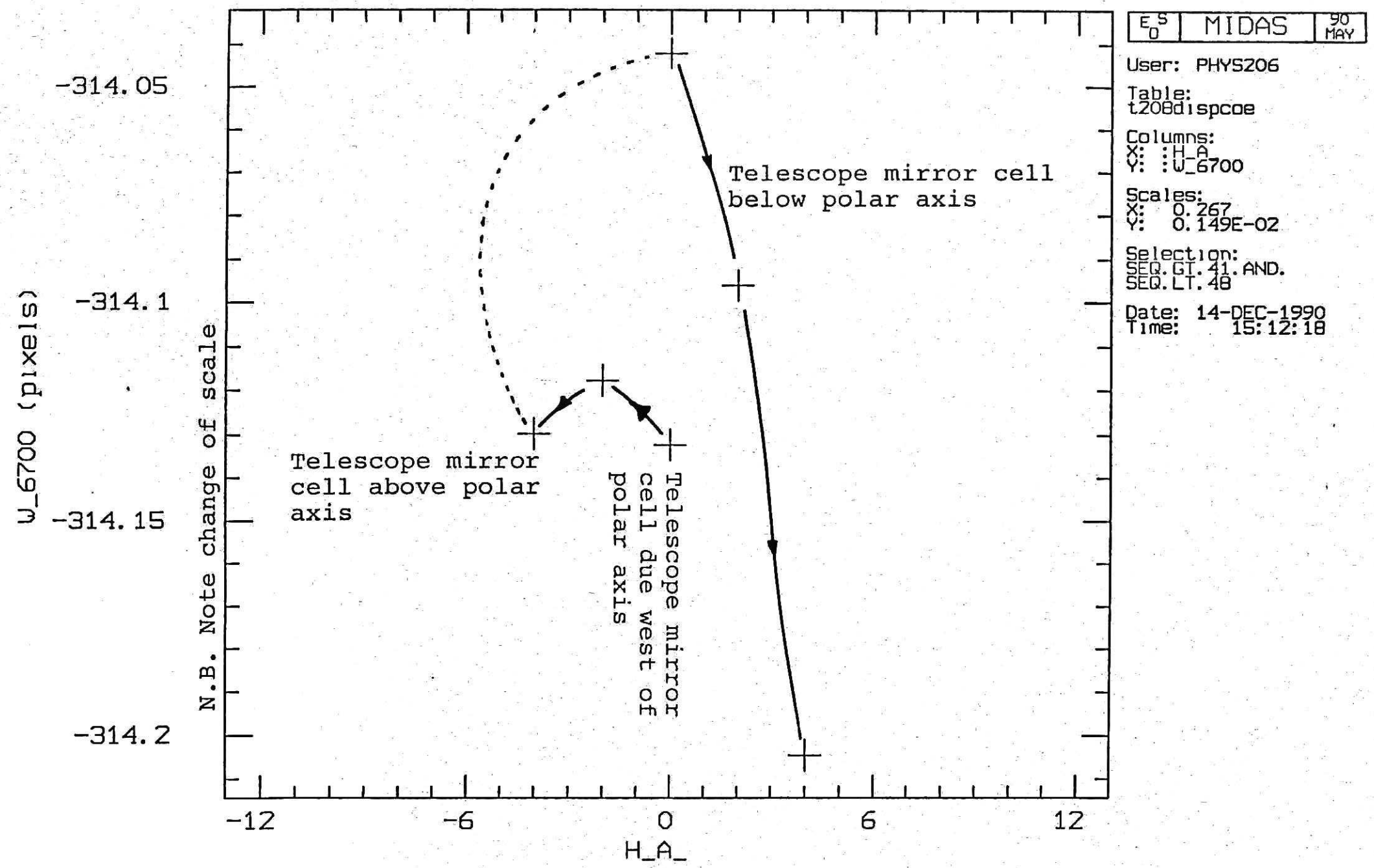


FIGURE 4 : Flexure tests in the meridian (telescope mirror cell due west of polar axis)

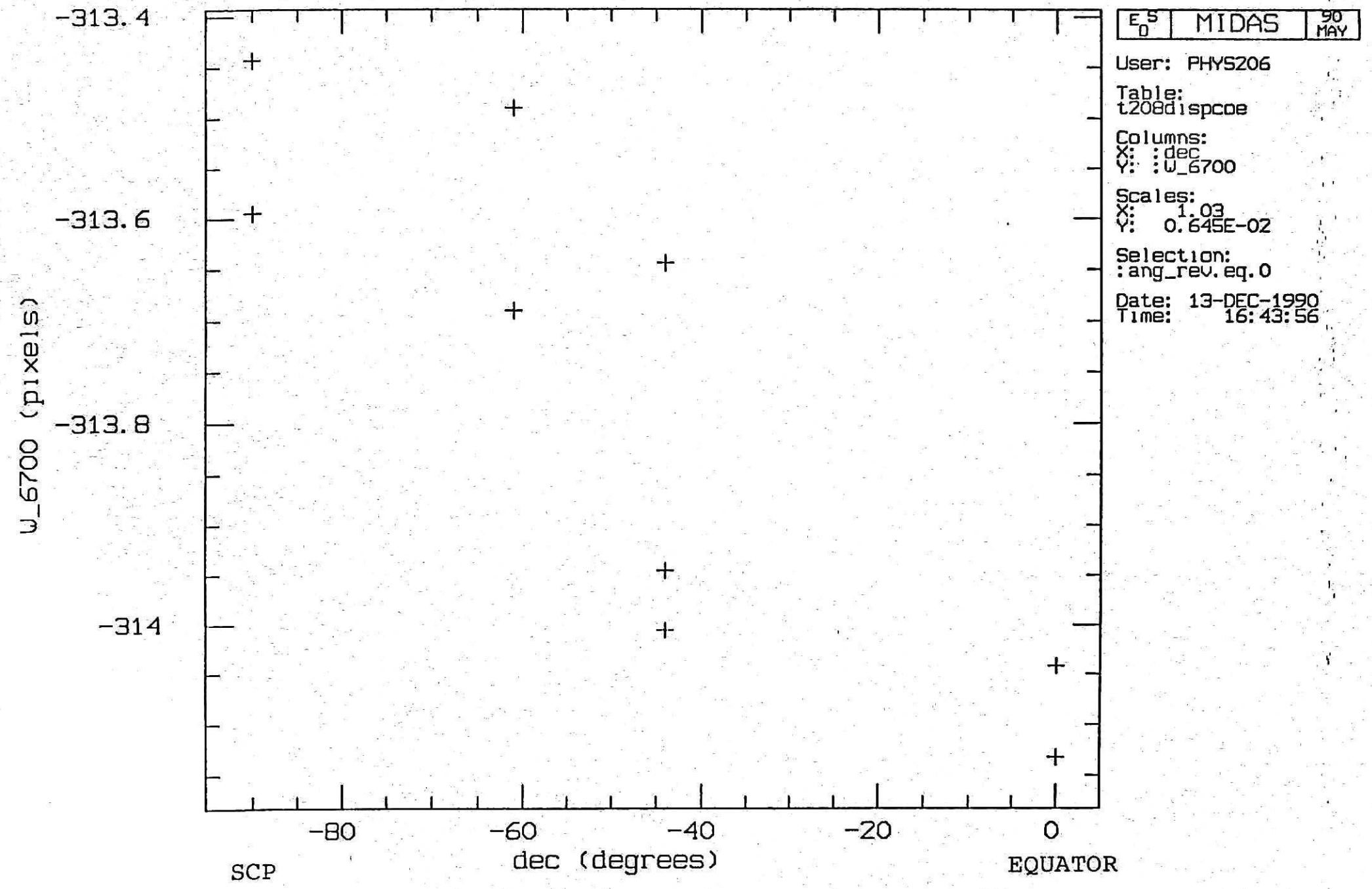
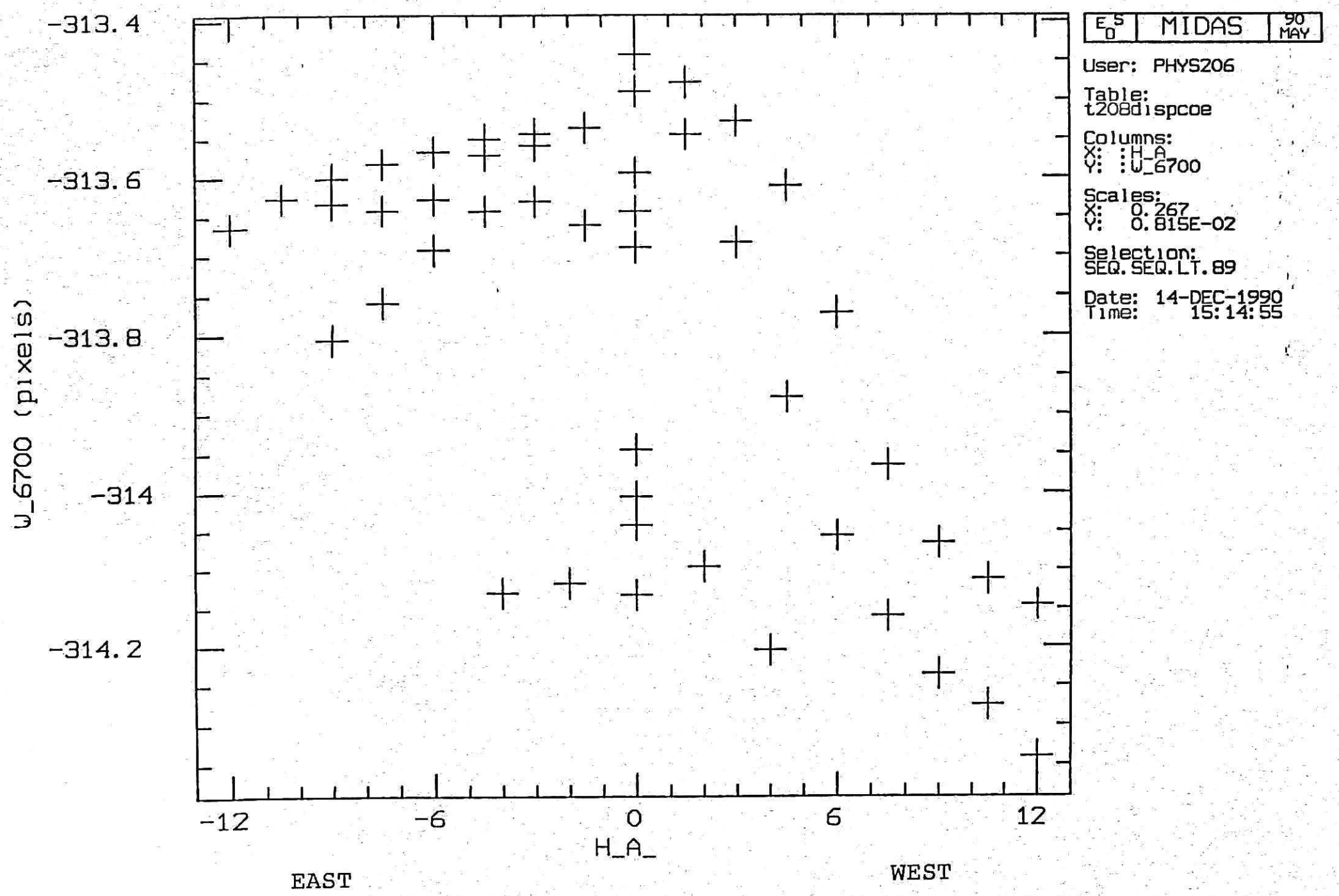


FIGURE 5 : The data of Figures 1-4 all plotted on the same graph



University of Canterbury Department of Physics & Astronomy

Mt John University Observatory

Mt John Photometrics CCD System

Use and Performance Note Number 5

TEMPERATURE SENSITIVITY OF THE CE200 ELECTRONICS UNIT

A.C.Gilmore & W.Tobin

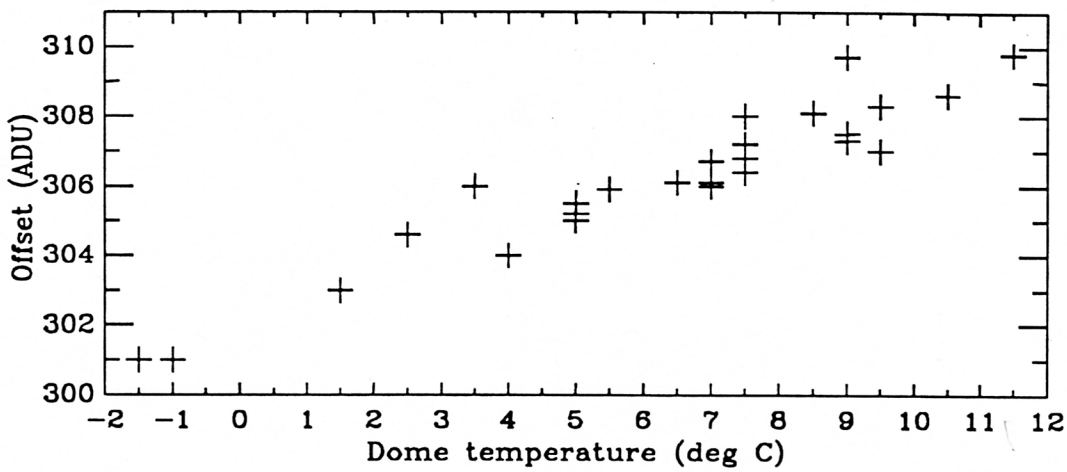
1991 January 23

These Notes are intended for guidance only: individual observers have the sole responsible for the integrity of their own data. Users of the CCD system are encouraged to summarize the performance that they obtain in a Note in this series. Contact Dr. W. Tobin to be allocated a series number.

TEMPERATURE SENSITIVITY OF THE CE200 ELECTRONICS UNIT

A C Gilmore & W Tobin

1991 January 23



The graph shows dark or offset (i.e. no exposure to light) signals obtained with the Mt John CCD system during 1990 September-November. The CCD chip temperature was in all cases approximately -110 °C. It can be seen that the offset level correlates with the dome temperature, consistent with the behaviour reported for a similar CCD system at the University of Toronto Southern Observatory (McCall, M.L., English, J., Shelton, I.: 1989, *J. Roy. Astron. Soc. Canada*, **83**, 179-206). The offset level increases by ~0.7 ADU/°C.

The offset signal includes ~10 ADU that come from the 70 ms illumination of the LED preflash ring bolted to the CH210 dewar. Since LED output typically varies by ~1%/°C, and anyway *dims* for higher temperatures, the offset variation cannot be due to preflash variations.

Since the electronics within the CH210 dewar are thermostatted, it would seem most likely that the offset variation arises within the CE200 electronics box. At this time it is not known whether the variation is purely in the offset (as claimed by the Canadian authors) or whether it also affects the system gain.

On 1990 September 1 the Mt John CCD acquisition software (loaded with **lf mtjohn**) was modified to keep track of the varying offset and to warn of its change. Each use of **dark** or **bias** calculates the mean value of the central 50 × 50 pixels of the area read out (or smaller area if less than 50 × 50 pixels are read out). This mean offset offset level is then displayed to the observer and stored in the image header.

Every use of a word that involves termination of an exposure (**readout**, **obs**, **hear**, **lisse**, etc.) causes a bias frame to be read out immediately thereafter. The mean offset of this frame is calculated in the same way as for a **dark** or **bias** frame, and the offset level is stored in the header of the image which immediately preceded it.

When **median** is used to create a cosmic-ray-free dark frame (or any other sort of frame) the mean mean offset is calculated and stored in the median frame image header.

Whenever **-dark** is used to subtract a dark frame from an image frame, the associated offset values are compared. If they differ by more than 2 ADU a warning message is presented to the observer, who may then wish to acquire a new dark image.

Users should note the difference between the **bias** and **dark** commands. A true, zero-duration exposure is obtained with **bias**. The exposure duration in deciseconds is required on the stack for **dark**. The minimum duration of dark exposure that accumulates before readout begins is 2 decisecond, whatever the value found on the stack. Since the thermal generation of charge in the CCD chip at cryogenic temperatures is less than 1 electron $pixel^{-1}$ $minute^{-1}$, the practical difference between **bias** and **dark** at cryogenic temperatures is negligible (except of course, for the accumulation of cosmic rays).

Both **dark** and **bias** illuminate the LED flash ring. The Photometrics Image Type parameter is set to 1 with **dark** and 2 with **bias**.

University of Canterbury Department of Physics & Astronomy

Mt John University Observatory

Mt John Photometrics CCD System

Use and Performance Note Number 6

THE BOLLER & CHIVENS INTERMEDIATE-RESOLUTION SPECTROGRAPH

W. Tobin

1991 February 4

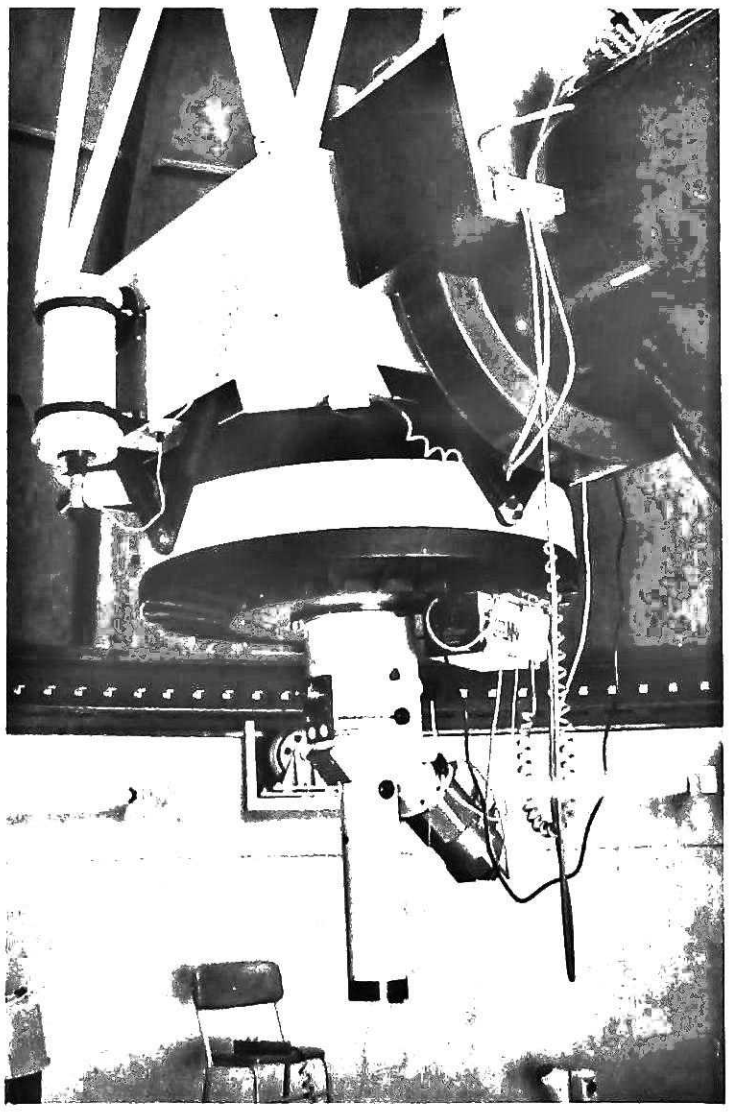
These Notes are intended for guidance only: individual observers have the sole responsible for the integrity of their own data. Users of the CCD system are encouraged to summarize the performance that they obtain in a Note in this series. Contact Dr. W. Tobin to be allocated a series number.

University of Canterbury
Department of Physics
Mt John University Observatory

Mt John Photometrics CCD System

Use and Performance Note
Number 6

THE
BOLLER & CHIVENS
INTERMEDIATE-RESOLUTION
SPECTROGRAPH



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be allocated a series number.

THE BOLLER & CHIVENS INTERMEDIATE-RESOLUTION SPECTROGRAPH

W Tobin

1991 February 4

The Boller & Chivens Type 27273 f/13.5 intermediate-resolution spectrograph at Mt John has been temporarily modified with a 200 mm focal-length camera lens so that the Photometrics CCD system can be used as the detector. A sketch of the arrangement is given in Figure 1. Because of cable restrictions, the spectrograph and CCD dewar must be mounted on the Mt John Boller & Chivens telescope with the slit-viewing eyepiece at northern azimuths, but may be mounted in any orientation on the McLellan 1 m telescope. With the eyepiece mounted north or south, the slit length is east-west. A quartz-halide flashlamp bulb has also been installed to provide the 'smooth-field' source needed for the removal of high-spatial-frequency gain variations in the CCD. The smooth-field bulb is mounted close to the helium-argon wavelength-calibration lamp within a common housing. The desired lamp is selected by the appropriate application of electrical power.

The CCD is mounted with its long axis (13.3 mm) nearly parallel to the dispersion direction. Bolt holes are provided so that the CCD diagonal (15.9 mm) can be aligned parallel to dispersion, but users should note that such an alignment is likely to complicate the reduction software requirements considerably.

Gratings are available ruled with 150, 300 and 600 lines mm^{-1}. The resulting dispersions are nearly linear: approximate values are given in Table I.

Table I : Available dispersions

Grating	Order	Å/mm	Å/pixel	km s^{-1}/pixel	Note
600	1st IR	55	1.3	~50	Estimated
	2nd red	28	0.6	~30	Measured
	3rd blue	18	0.42	~30	Measured
300	1st IR	145	3.3	~130	Measured
	2nd red	70	1.6	~75	Measured
	3rd blue	45	1.05	~75	Measured
150	1st IR	290	6.7	~260	Estimated
	2nd red	140	3.2	~150	Estimated
	3rd blue	90	2.1	~150	Estimated

Three order separating filters are currently available: 1 mm Schott BG12 (blue), 2 mm Schott RG630 (red), and 3 mm Corning 3-71 (yellow). Two filter holders are available. The BG12 filter is very fragile, and should not normally be removed from its holder, but it is safe to exchange the thicker red and yellow filters in the other holder.

The camera lens is a commercial 35 mm camera lens, and suffers from chromatic aberration, and poor focus quality in the infra-red and ultraviolet. With the 600 line mm^{-1} grating, the chromatic aberration in the optical across the CCD length is sufficiently small that the varying focal position can be compensated for adequately by refocusing the spectrograph. With the 300 line mm^{-1} grating, however, it is sometimes necessary to tilt the CCD dewar by inserting shims between the dewar and the camera lens assembly (users should ensure this is done on the appropriate side of the mylar gasket in order to maintain electrical isolation of the dewar). With both the 300 and 600 line mm^{-1} gratings the plane of least poor infra-red focus may be outside the range available with the spectrograph focus knob, in which case shims will also be needed (to move the CCD out). Available slit and decker sizes are given in Table II.

With the 300 line mm^{-1} grating and the available order separating filters, the available wavelength range is covered by the 5 grating/filter combinations listed in Table III. The corresponding wavelength ranges can be read from Figures 2-11, which map the helium-argon wavelength-calibration arc and suggest identifications for some of the lines. Figures 3, 5, 7, 9 and 11 indicate lines and wavelengths which at this dispersion appear to give a good fit to a third-order polynomial: r.m.s. deviations are listed in Table III for exposure times and signal levels shown in Figures 2-11. (Note these exposure times and signal levels refer to **0 cgain**.) The r.m.s. derivations obtained in second order are surprisingly small. Users should scrutinise Use and Performance Note No. 4 for details of spectrograph flexure.

Several Forth observing words have been written specifically for use with the Boller & Chivens spectrograph and are available once **lf mtjohn** has been performed. They, and certain other relevant words, include:

B&Cs - sets instrument details for image headers. It prompts for values or changes to the grating selected (e.g. 300), the grating angle (in format -DD.MM, e.g. -12.30), the real slit width in micrometre (e.g. 112 - note the values indicated on the spectrograph dial are *half* the actual values), and the collimator focal setting (e.g. 505).

BG12 Words for indicating the installed order-separating filter
RG630
C371
No_filter
Quartz

!fmt sets CCD read-out area and binning. Requires six parameters on stack. See Photometrics Forth Manual.

target prompts for (changed) target name. This target-name is stored in a register and written into image headers.

tcomment to add comments into an image header after the target name.

n lisse obtains an n decisecond exposure (which should be of the smooth-field lamp). It writes 'SMOOTH_FIELD for target-name' into the image header. (Lisse = French for 'smooth'.)

normalise scales the current 'smooth' image so that the mean pixel value (bar a 10-pixel wide border) is 10000. Useful only if the area read out with **!fmt** and **lisse** is smaller than the spectrograph decker.

median obtains the median of three images. Prompts for cache numbers.

m -dark subtracts the image in cache m from the current image. Warns if the image to be subtracted is not a dark frame.

m smoothfield multiplies the current image by 10000 and divides by the image in cache m (which should be a possibly-normalised smooth field). As with all commands that perform image arithmetic, this command performs integer arithmetic. The results may be questionable if the signal levels in the target spectrum are low (see below).

n hear obtains an n decisecond exposure (which should be of the helium-argon wavelength-calibration lamp). It writes 'HeAr for target-name' into the image header.

Observers should consider *very carefully* what parameter value they wish to adopt for **cgain**, especially if they are observing faint objects. In addition to the question of read-out noise, digitisation noise may be significant at low signal levels if **cgain** is inappropriately set. Further, at low data numbers smooth-fielding with **lisse** may not work satisfactorily because the command uses integer arithmetic. (One possible solution to this problem is to multiply images by a constant using **c*** before applying **lisse**.)

Figure 12 shows some sample spectra taken with the 300 line mm^{-1} grating at **0 cgain** (1 ADU $\approx$ 20 electrons) and reduced using MIDAS. The limit of observation for ~10^4 electron/pixel in a total of an hour's exposure at all grating settings is of the order of 11th magnitude on the McLellan telescope. (Long exposures should be broken to facilitate removal of cosmic rays.) The shape of the continua in Figure 12 of course involve division by the (normalised) smooth-field image (especially obvious for β Leporis).

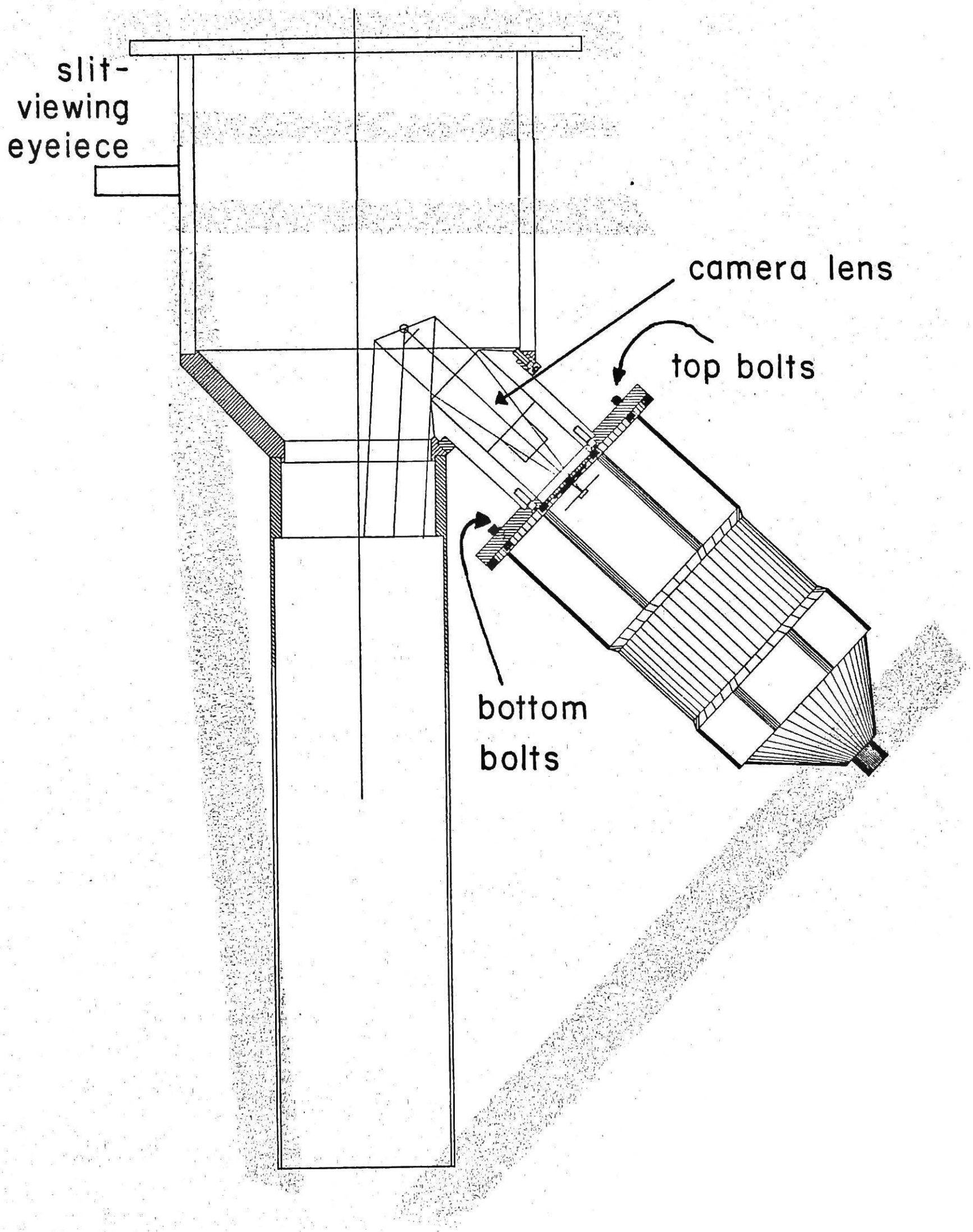


Fig. 1: Spectrograph modifications

Table II : Slits and deckers

Indicated slit width	Real slit width	Real slit width f/13.5 telescope D = 0.61 m	D = 1.0 m	Projected width at CCD	
20 μm	40 μm	0.4 arc sec	0.6 arc sec	11 μm	0.5 pixels
28	56	0.5	0.9	16	0.7
40	80	0.7	1.2	23	1.0
56	112	1.0	1.7	32	1.4
80	160	1.5	2.4	45	2.0

Decker length		Decker length D = 0.61 m	D = 1.0 m	Comparison windows' spacing †
1.5 mm	20 pixels	38 arc sec	23 arc sec	2.5 mm
3	40	75	45	4.0
13	160	325	200	-
25 ††	270	630	380	-

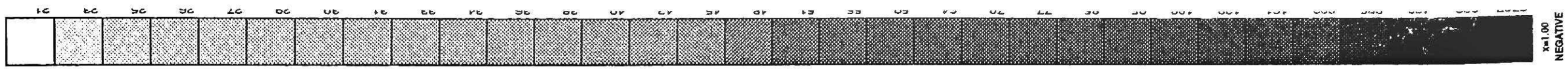
† Use of comparison windows not recommended with the CCD. Obtain wavelength-calibration arcs on a separate frame.

†† The full length of the 25 mm decker cannot be seen with the present slit-viewing eyepiece assembly.

Table III : 300 line mm^{-1} grating

Order	Filter	Grating	Shims †		R.M.S. of 3rd-order polynomial fit to He-Ar arc		
			Top	Bottom			
1st IR (poor focus)	RG630	-7°00′	1 mm	1 mm	0.03 nm	0.3 Å	10 km s^{-1}
		-8°25′	1 mm	1 mm	0.017 nm	0.17 Å	6 km s^{-1}
2nd red	C3-71	-11°45′	-	-	0.006 nm	0.06 Å	3 km s^{-1}
		-13°15′	1 mm	0.5 mm	0.004 nm	0.04 Å	2 km s^{-1}
3rd blue	BG12	-12°30′	0.5 mm	0.5+1.2 mm	0.007 nm	0.07 Å	5 km s^{-1}

† It may be possible to improve the focus quality with different shim thicknesses. Users should use the cited values as first approximations.



COLUMN OFFSET: 70 ; ROW OFFSET: 0 ; No.COLS: 130 ; No.ROWS: 576 ; COLUMN BINNING: 1 ; ROW BINNING: 1 ; GAIN: 0 ; IMAGE TYPE 3

-DRK RA= DEC= (1990.9) MJUO LST=06:12:44 X= HA= h m

HeAr **3rd-ORDER BLUE**

Department of Physics

HP LaserJet III

University of Canterbury *Mt John University Observatory*

Thomson TH7882CDA Charge-Coupled Device

Wavelengths: CRC Handbook of Chemistry and Physics, 68th Edition 1987-88. Air values.

poor focus

ArI 427.2169
ArII 428.2898
ArII 437.5954

ArII 392.8623
ArI 394.7505, 394.8979
HeI 396.4729
ArII 401.3857
HeI 402.6191 (402.636)
ArII 404.2894, ArI 404.4418
ArII 407.2005 , 407.2385
ArII 410.3912
HeI 412.082, 412.099
ArII 413.1724
HeI 414.376
(ArII 415.6086), ArI 415.8590
ArI 418.1884
ArI 419.0713, 419.1029
ArI 419.8317, 420.0674
ArII 422.6988, 422.8158
ArII 423.7220
ArI 425.9362
ArI 426.6286, ArII 426.6527
ArII 427.7528
ArI 430.0101 (ArII 430.0650)
ArII 430.9239
ArII 433.1200, 433.2030
ArI 433.3561, 433.5338
ArII 434.8064
ArII 437.0753, 437.1329
ArII 437.9667
HeI 438.7929
ArII 440.0097, 440.0986
ArII 442.6001
ArII 443.0189, 443.0996
HeI 447.1479, 447.168
ArII 448.1811
ArI 451.0733

0 100 200 300 400 500

CORRECTED MEAN [UT] 15:13:05
JULIAN DAY 2448211.1341
ENDED
EXPOSURE 200.0 s
OFFSET 309.50
BEGUN 15:11:59-
DECISECONDS 2000 ds
ID_TICKS 65868191919
CONVERTED TO POSTSCRIPT FILE
T205_007.PTM --->.PS at 29-JAN-91 10:23:31

FILTER **BG12**
GRATING 300
GRATING ANGLE -12°30'
REAL SLIT WIDTH 112
COLL'R FOCUS 505
RECORDED ACQUISITION DATE & TIME 1990-Nov-15 15
INSTRUMENT **B&Cs**
UT-CCD -34.2 Intpln
INPUT FILE **T205_007.PTM**
TELESCOPE B&C
OBSERVER wtrh
ACQUISITION SOFTWARE MtJohn

Fig. 2

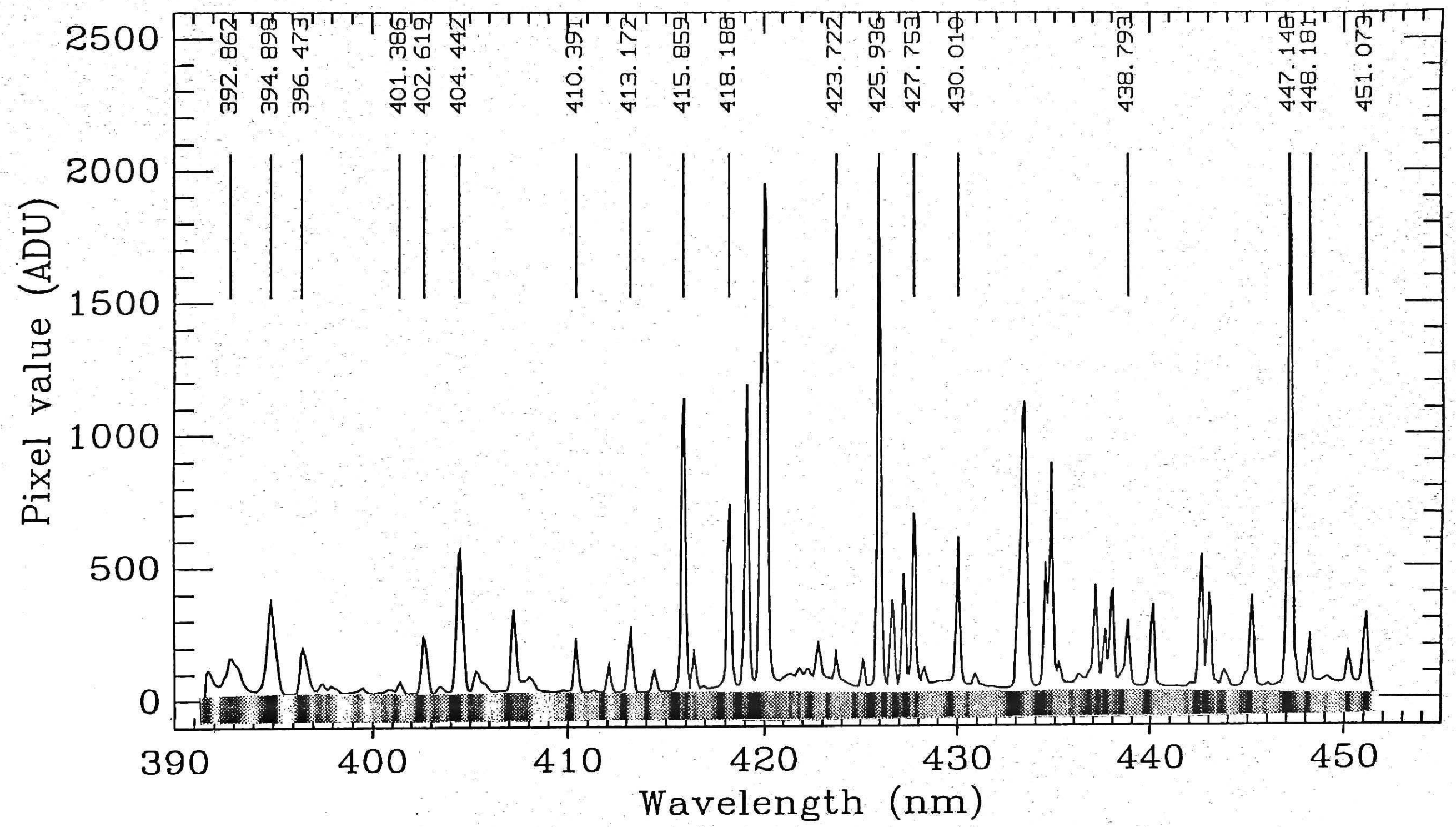

Pixel value (ADU)
2500
2000
1500
1000
500
0
390
400
410
420
430
440
450
Wavelength (nm)
392.862
394.898
396.473
401.386
402.619
404.442
410.391
413.172
415.859
418.188
423.722
425.936
427.753
430.010
438.793
447.148
448.181
451.073

Fig. 3

University of Canterbury

Mt John University Observatory

Department of Physics

Thomson TH7882CDA Charge-Coupled Device

HP LaserJet III

HeAr 2nd-ORDER RED

-DRK RA= DEC=

Wavelengths: CRC Handbook of Chemistry and Physics, 68th Edition 1987-88. Air values.

ArI 549.5874
ArI 550.6113
ArI 555.8702
ArI 557.2541
ArI 560.6733
ArI 565.0704
ArI 573.9520
ArI 583.4263
ArI 586.0310
HeI 587.562, 587.597
ArI 591.2085
ArI 592.8813
ArI 594.2669
ArI 598.7302
ArI 599.8999
ArI 603.2127
ArI 604.3223
ArI 605.9372
ArI 610.5635
ArII 611.4923
ArI 614.5441
ArII 617.2278, ArI 617.3096
ArI 621.2503
ArI 621.5938
ArII 624.3120
ArI 629.6872
ArI 630.7657
ArI 636.9575

500 400 300 200 100 0

300 200 100 0

Fig. 4

FILTER	GRATING	RECORDED ACQUISITION DATE & TIME BEGUN	ENDED	CORRECTED MEAN [ST]
C371	300	1990-Nov-13 08:32:55-		08:33:12
	GRATING ANGLE	INSTRUMENT DECISECONDS	EXPOSURE	JULIAN DAY
	-11°45′	B&Cs 1000 ds	100.0 s	2448208.8564
TELESCOPE OBSERVER	REAL SLIT WDTH	UT-CCD ID_TICKS	OFFSET	
B&C wtrh	56	-33.0 Intpln 658485175	309.43	
ACQUISITION SOFTWARE	COLL'R FOCUS	INPUT FILE CONVERTED TO POSTSCRIPT FILE		
MtJohn	240	T203_006.PTM -->.PS at 29-JAN-91 10:31:42		

COLUMN OFFSET: 60 ; ROW OFFSET: 0 ; No.COLS: 160 ; No.ROWS: 576 ; COLUMN BINNING: 1 ; ROW BINNING: 1 ; GAIN: 0 ; IMAGE TYPE 3

(1990.9) MJUO LST=23:23:52 X= HA= h m

x=1.00 NEGATIVE

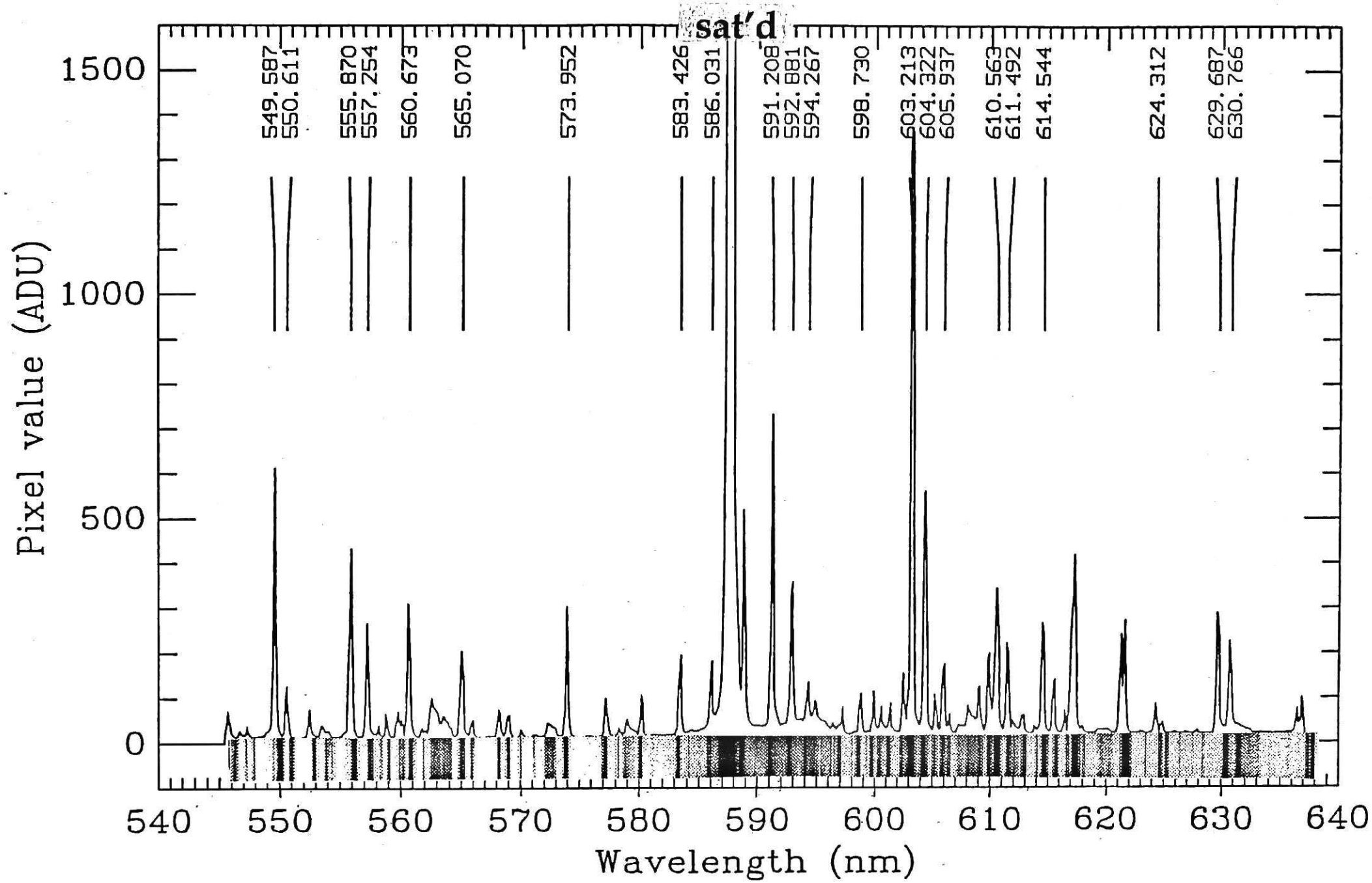

sat'd
549.587
550.611
555.870
557.254
560.673
565.070
573.952
583.426
586.031
591.208
592.881
594.267
598.730
603.213
604.322
605.937
610.563
611.492
614.544
624.312
629.687
630.766
1500
1000
500
0
Pixel value (ADU)
540
550
560
570
580
590
600
610
620
630
640
Wavelength (nm)

Fig. 5

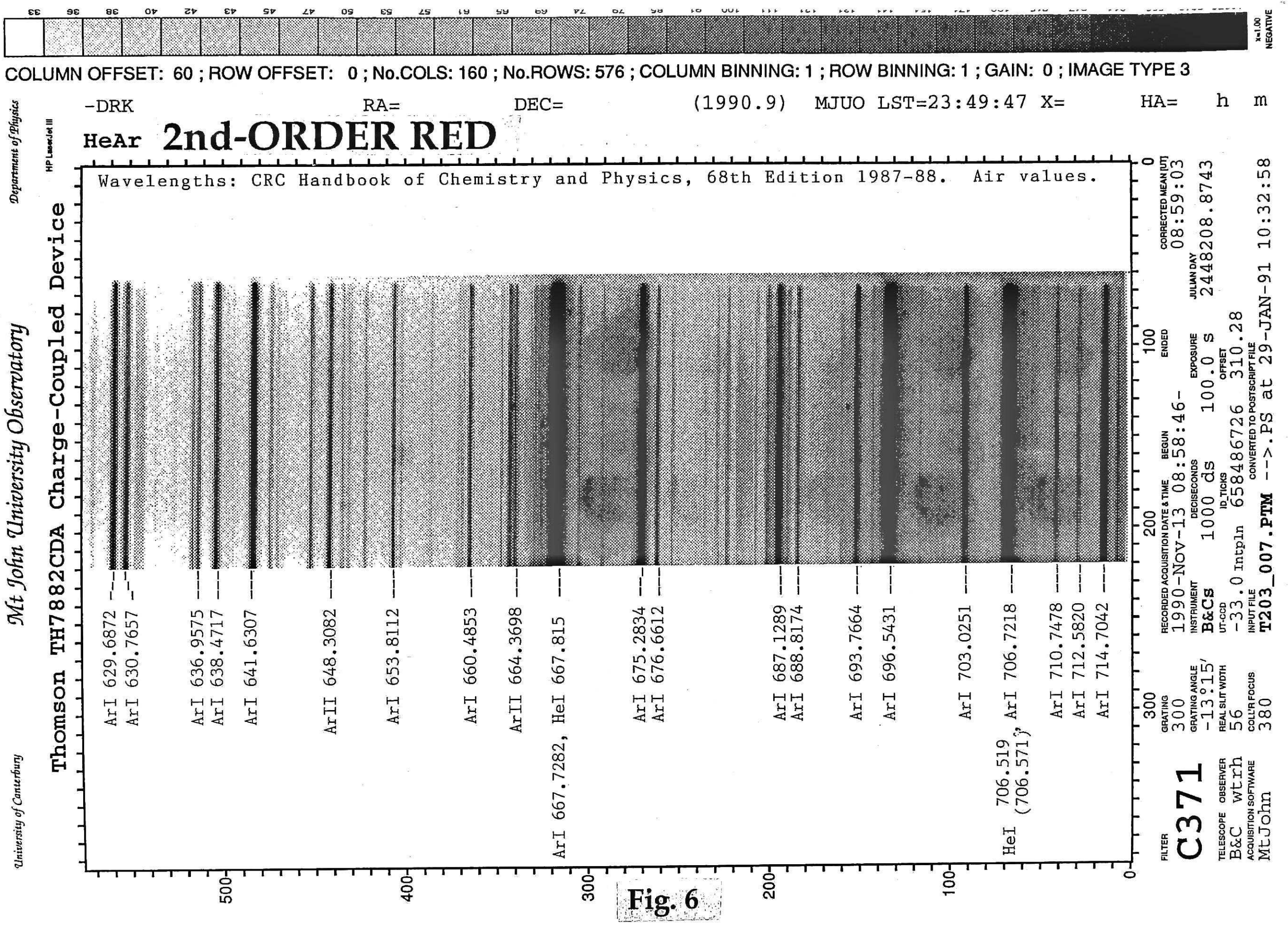

COLUMN OFFSET: 60 ; ROW OFFSET: 0 ; No.COLS: 160 ; No.ROWS: 576 ; COLUMN BINNING: 1 ; ROW BINNING: 1 ; GAIN: 0 ; IMAGE TYPE 3
-DRK RA= DEC= (1990.9) MJUO LST=23:49:47 X= HA= h m
HeAr 2nd-ORDER RED
Wavelengths: CRC Handbook of Chemistry and Physics, 68th Edition 1987-88. Air values.
Thomson TH7882CDA Charge-Coupled Device
ArI 629.6872
ArI 630.7657
ArI 636.9575
ArI 638.4717
ArI 641.6307
ArII 648.3082
ArI 653.8112
ArI 660.4853
ArII 664.3698
ArI 667.7282, HeI 667.815
ArI 675.2834
ArI 676.6612
ArI 687.1289
ArI 688.8174
ArI 693.7664
ArI 696.5431
ArI 703.0251
HeI 706.519 (706.571)
ArI 706.7218
ArI 710.7478
ArI 712.5820
ArI 714.7042
BEGUN 08:58:46-
ENDED 08:59:03
EXPOSURE 100.0 s
JULIAN DAY 2448208.8743
OFFSET 310.28
CONVERTED TO POSTSCRIPT FILE
-->.PS at 29-JAN-91 10:32:58
FILTER C371
GRATING 300
GRATING ANGLE -13°15'
REAL SLIT WIDTH 56
COLL'R FOCUS 380
RECORDED ACQUISITION DATE & TIME 1990-Nov-13 08:58
INSTRUMENT B&Cs
DECISECONDS 1000 ds
UT-CCD -33.0 Intpln
ID_TICKS 6584867
INPUT FILE T203_007.PTM
TELESCOPE B&C
OBSERVER wtrh
ACQUISITION SOFTWARE MtJohn
Department of Physics
University of Canterbury
Mt John University Observatory
HP LaserJet III

Fig. 6

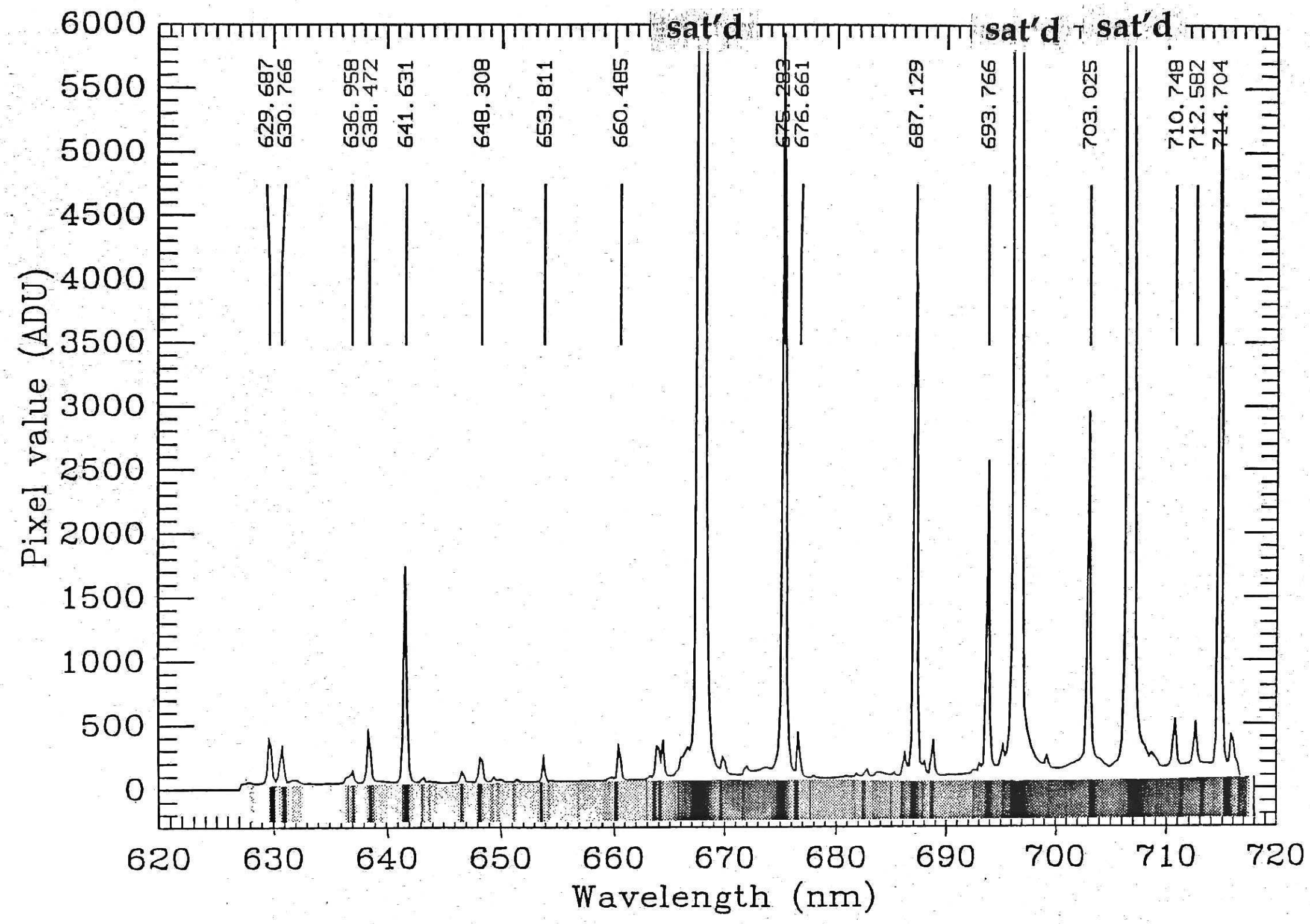
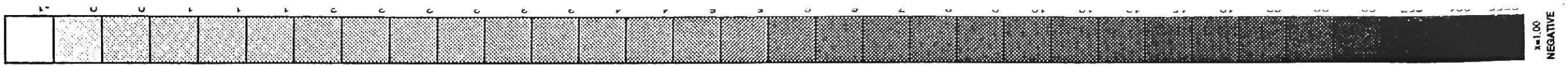

sat'd
sat'd
sat'd
629.687
630.766
636.958
638.472
641.631
648.308
653.811
660.485
675.283
676.661
687.129
693.766
703.025
710.748
712.582
714.704
Pixel value (ADU)
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
620
630
640
650
660
670
680
690
700
710
720
Wavelength (nm)

Fig. 7



COLUMN OFFSET: 70 ; ROW OFFSET: 0 ; No.COLS: 130 ; No.ROWS: 576 ; COLUMN BINNING: 1 ; ROW BINNING: 1 ; GAIN: 0 ; IMAGE TYPE 3

-DRK RA= DEC= (1990.9) MJUO LST=02:36:59 X= HA= h m

HeAr **1st-ORDER INFRA-RED**

Wavelengths: CRC Handbook of Chemistry and Physics, 68th Edition 1987-88. Air values.

Filter cut-off

ArI 641.6307 ?

(ArI 667.7282) HeI 667.815

ArI 675.2834

ArI 687.1289

ArI 693.7664

ArI 696.5431

ArI 703.0251

HeI 706.519, ArI 706.7218
(706.571)

ArI 714.7042

ArI 720.6980

(ArI 727.2936) HeI 728.135

(ArII 738.0426) ArI 738.3980

ArI 750.3869, 751.4652

ArI 763.5106

ArI 772.3761, 772.4207

ArI 789.1075

ArI 794.8176

Thomson TH7882CDA Charge-Coupled Device

Mt John University Observatory

University of Canterbury

Department of Physics

HP LaserJet III

FILTER RG630 | GRATING 300 | GRATING ANGLE -7°00′ | INSTRUMENT B&Cs | REAL SLIT WIDTH 56 | UT-CCD -34.1 Intpln | COLL'R FOCUS 470 | INPUT FILE T203_076.PTM | ACQUISITION SOFTWARE MtJohn | TELESCOPE OBSERVER B&C wtrh

RECORDED ACQUISITION DATE & TIME 1990-Nov-15 11:38:29- | DECISECONDS 20 ds | ID_TICKS 658669109 | CONVERTED TO POSTSCRIPT FILE --->.PS at 29-JAN-91 10:24:41

BEGUN 11:37:56 | EXPOSURE 2.0 s | OFFSET 311.45 | ENDED | JULIAN DAY 2448210.9847 | CORRECTED MEAN [UT]

Fig. 8

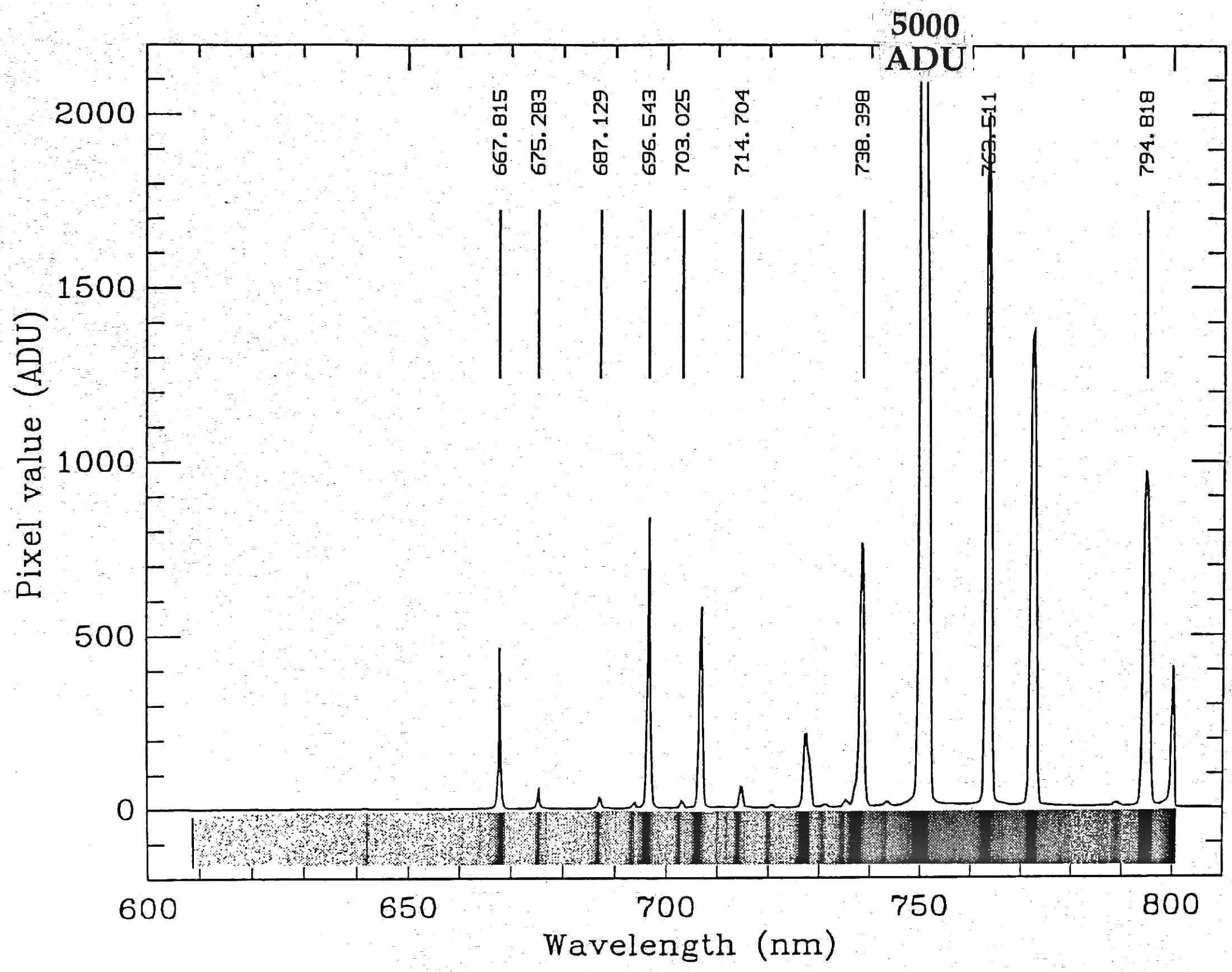

5000
ADU
667.815
675.283
687.129
696.543
703.025
714.704
738.398
763.511
794.818
2000
1500
1000
500
0
Pixel value (ADU)
600
650
700
750
800
Wavelength (nm)

Fig. 9

University of Canterbury

Mt John University Observatory

Department of Physics

Thomson TH7882CDA Charge-Coupled Device

HP LaserJet III

HeAr 1st-ORDER INFRA-RED

RA= DEC=

(1990.9) MJUO LST=16:46:33 X= HA= h m

Wavelengths: CRC Handbook of Chemistry and Physics, 68th Edition 1987-88. Air values.

COLUMN OFFSET: 70 ; ROW OFFSET: 0 ; No.COLS: 130 ; No.ROWS: 576 ; COLUMN BINNING: 1 ; ROW BINNING: 1 ; GAIN: 0 ; IMAGE TYPE 3

ArI 750.3869, 751.4652 ---

ArI 763.5106 ---

ArI 772.3761, 772.4207 ---

ArI 794.8176 ---

ArI 800.6157 ---

ArI 801.4786 ---

ArI 810.3693 ---

ArI 811.5311 ---

ArI 826.4522 ---

ArI 840.8210 ---

ArI 842.4648 ---

ArI 852.1442 ---

ArI 866.7944 ---

ArI 884.991 ---

ArI 912.2967 ---

ArI 919.4638 ---

ArI 922.4499 ---

ArI 929.1531 ---

500 400 300 200 100 0

300 200 100 0

FILTER	GRATING	RECORDED ACQUISITION DATE & TIME BEGUN	ENDED	CORRECTED MEAN [UT]
RG630	300	1990-Nov-15 01:49:39-		01:49:06
GRATING ANGLE	INSTRUMENT	DECISECONDS	EXPOSURE	JULIAN DAY
-8°25′	B&Cs	20 ds	2.0 s	2448210.5758
TELESCOPE OBSERVER	REAL SLIT WDTH	UT-CCD	ID_TICKS	OFFSET
B&C rhwt	56	-33.9 Intpln	658633779	315.78
ACQUISITION SOFTWARE	COLL'R FOCUS	INPUT FILE	CONVERTED TO POSTSCRIPT FILE	
MtJohn	190	T203_052.PTM	-->.PS at 29-JAN-91 10:26:34	

x=1.00 NEGATIVE

Fig. 10

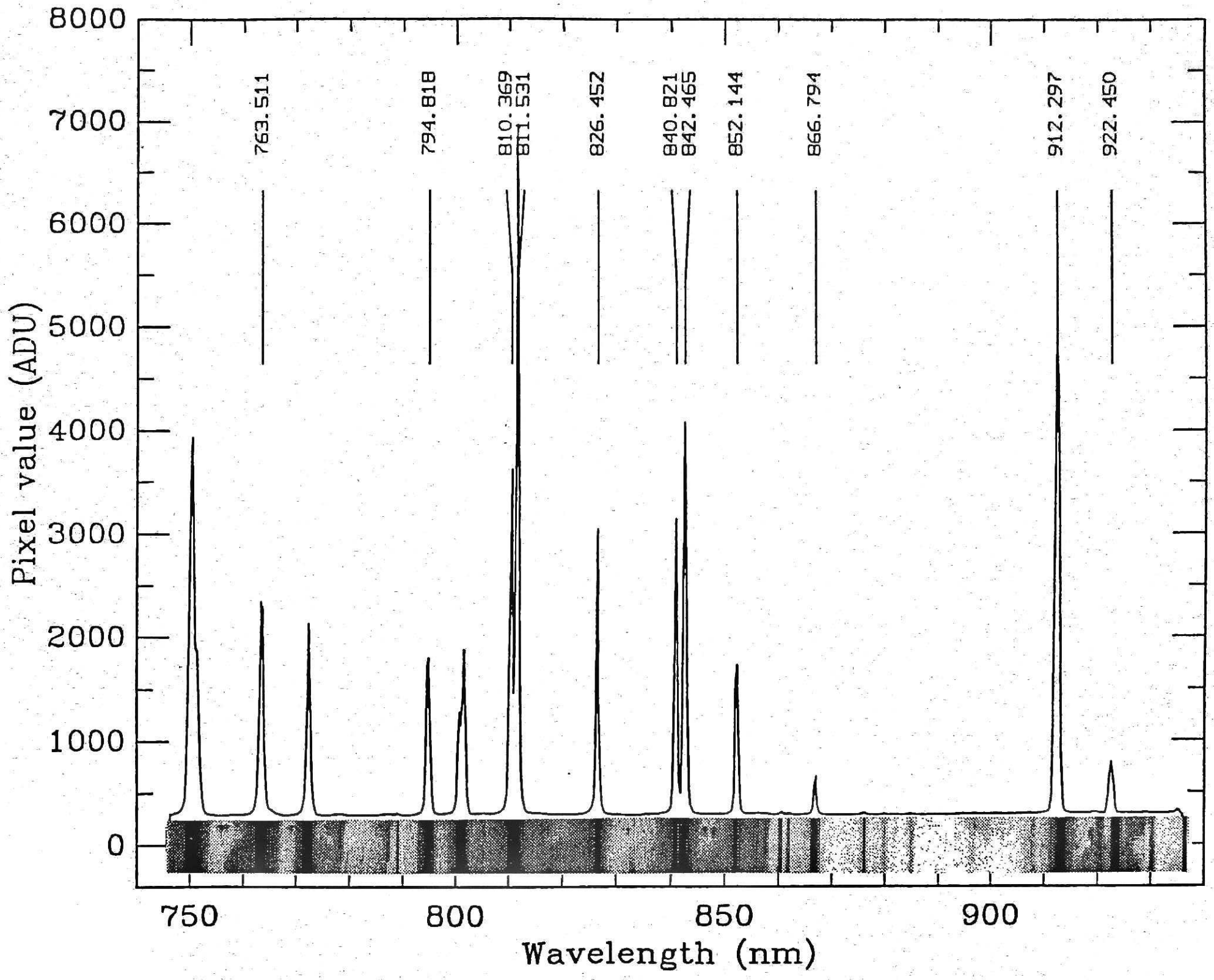

763.511
794.818
810.369
811.531
826.452
840.821
842.465
852.144
866.794
912.297
922.450
Pixel value (ADU)
8000
7000
6000
5000
4000
3000
2000
1000
0
750
800
850
900
Wavelength (nm)

Fig. 11

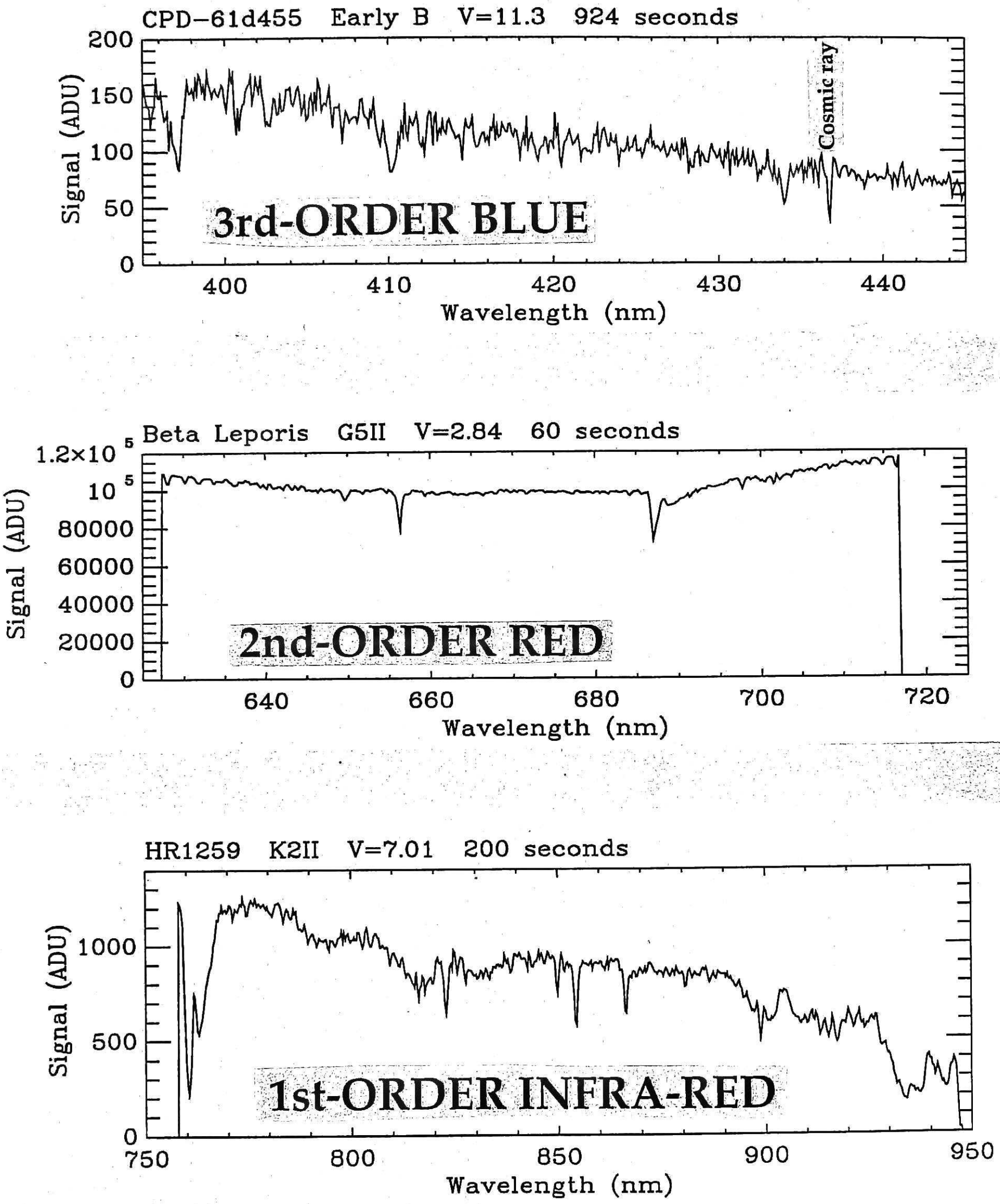


Fig. 12: A variety of stellar spectra

University of Canterbury Department of Physics & Astronomy

Mt John University Observatory

Mt John Photometrics CCD System

Use and Performance Note Number 7

TIME KEEPING ON THE PHOTOMETRICS CCD SYSTEM

W. Tobin

1991 April 6

These Notes are intended for guidance only: individual observers have the sole responsible for the integrity of their own data. Users of the CCD system are encouraged to summarize the performance that they obtain in a Note in this series. Contact Dr. W. Tobin to be allocated a series number.

TIME KEEPING ON THE PHOTOMETRICS CCD SYSTEM

W. Tobin

1990 April 6

As described in the 'Photometrics 3000 Forth Manual' Section 12.3.1, the Mt John CCD system derives time from a 'clock module'. This module is probably a 'Dallas SmartWatch', and maintains time even when the computer power is turned off. Interrupts generated by the clock module cause the updating of two 32-bit registers.

The first register, the 'Interrupt Service Register' contains the number of milliseconds since the Forth system was last loaded, and is accessible through **time ?**. The Interrupt Service Register is updated every 10 milliseconds. The second register is the 'Clock Time Register'. When the Forth system is loaded (with **25 load**) the clock module is read. The time is converted to the number of seconds since 1970 January 1 00:00:00 UT (leap years included but leap seconds excluded). The clock module interrupts are then used to update the Clock Time Register once every second. The Clock Time Register is accessible through **$tdate ?** and as a decimal number occupies 9 digits. This form is purportedly the same as the Unix definition of time. The Clock Time Register is also accessible via **prdate** and **prtime**, which output date and time to the terminal. **n pdt** will give the date and time corresponding to value **n** of the Clock Time Register.
Example: 123456789 pdt yields 29 Nov 73 21:33:09.

The routines supplied by Photometrics that underlie **pdt, prdate, prtime** and also **newdate** etc. (see below) were found to contain a logical error, which resulted in the years 1990, 1994, 1998 ... being taken as leap years while 1988, 1992, 1996 ... were not. This has been corrected (though the algorithm will still fail in 2000, which will be taken as a leap year).

Several improvements have been made to the time-keeping system as provided by Photometrics. They are invoked when the Mt John extensions are loaded with **lf mtjohn.**
At system start up, the Photometrics System only reads the clock module down to the seconds. Equally, the clock module is reset with **newdate** (superceded by **clockset** - see below) only down to the seconds. There is thus an o(1 second) uncertainty in times obtained from the Clock Time Register. Loading the mtjohn extensions synchronises the Clock Time Register to the on-the-second 'tick' of the clock module. Synchronisation can be achieved at any other time by typing **sync_on_rtc getclock.**

The commands **expose** and **readout** have been modified so that exposures begin and end only as the clock module ticks. Thus exposures obtained with these commands are an exact integral number of seconds long ... 399.00s, or 400.00s or 401.00s, but not 399.55s or 400.32s or 400.99s. The

exposure duration for an **expose - readout** sequence can be determined from the times of acquisition start and finish recorded in the image header. (They too are a mtjohn extension - the Photometrics system only records the time of **readout**.)

The clock module is not used to set the duration of images acquired with commands such as **n obs**, **n dark**, **n lisse**, etc. The timing for these exposures most probably derives from a microprocessor clock oscillator. Tests conducted in 1991 March found this clock to be running 4.3% fast. (This should be compared with the 4.7% fast running found for the very-similar Photometrics CCD system installed at the University of Toronto Southern Observatory - see McCall, M.L., English, J., Shelton, I.: 1989 *J. Roy. Astron. Soc. Canada* **83**, 179-206.) It is not known how uniform the rate of this clock is, and users should make appropriate tests if this quantity is of importance to them. Users attempting absolute photometry should not mix use of **obs** and **expose** & **readout**. Rather, they should define words such as **n temp**

: temp expose 50 - 10 * `ms` **readout ;**

in order to obtain short exposures timed by the clock module.

As a matter of policy, all instrument-related clocks at the Mt John University Observatory are set to Coordinated Universal Time. Users should ensure that the CCD clock is indeed set to UT, because UT is assumed by the VAX/VMS-based tape-reading software that calculates airmasses, julian time, etc.

The clock module does not of course run at precisely the correct rate, and in general both the date and time and the measurement of interval that it provides are wrong. The Mt John CCD clock module runs at a rate only ~1 part in 10^5 different from that of UT, so errors of exposure interval are unlikely ever to be of practical importance. However the accumulated error will rapidly become significant if it is desired to obtain e.g. variable star observations with acquisition times accurate to 0.0001 julian day (9 seconds).

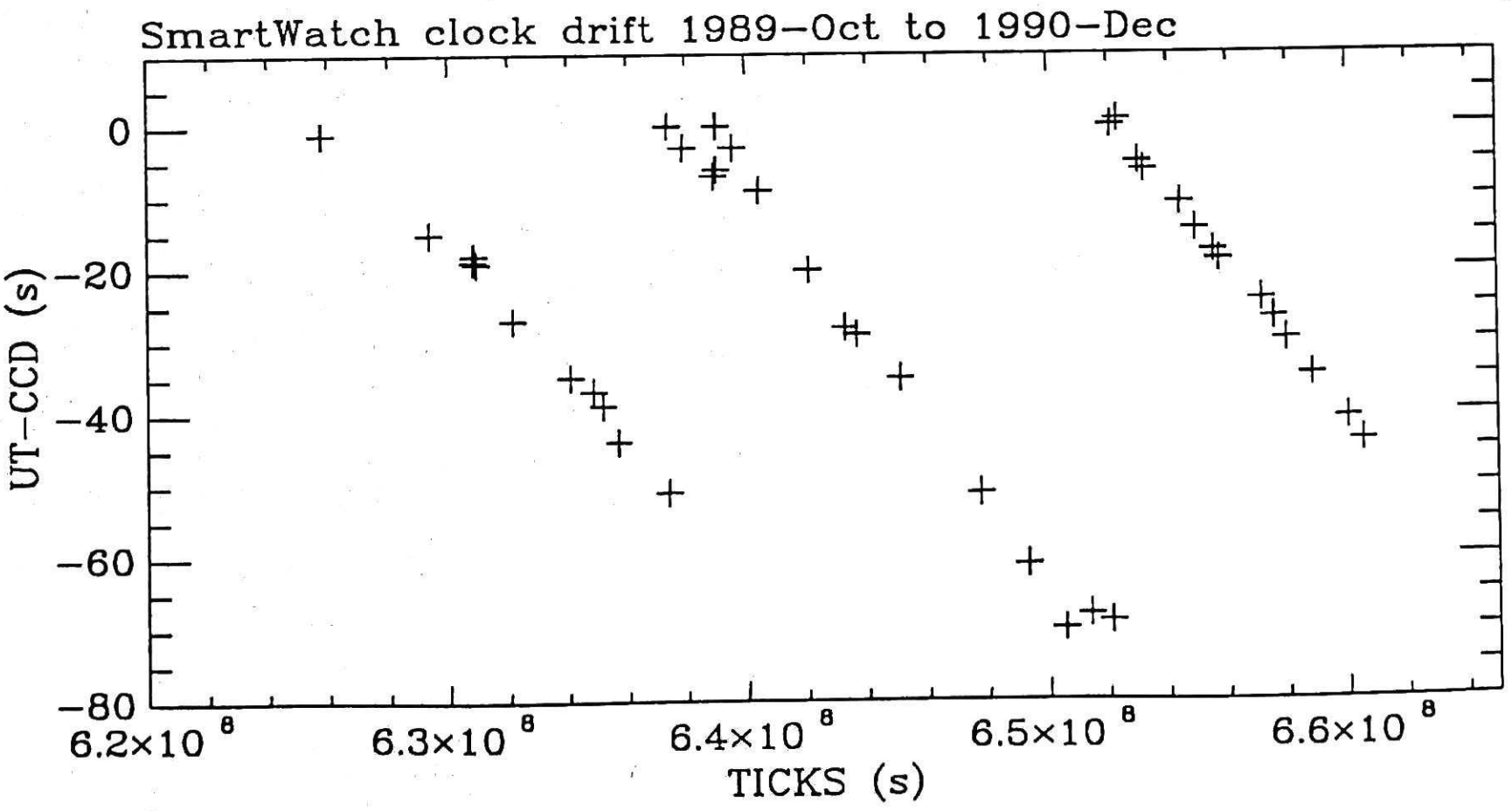
In principle an observer could frequently reset the clock module to UT using **newdate** (superceded by **clockset** - see below). However a preferable procedure is to monitor the clock drift and apply appropriate corrections to the recorded acquisition times: one cannot in any case know how frequently to reset the clock module without knowing its drift rate; abrupt changes of drift rate may be indicative of incipient clock module or other failure; and, at least in theory, one may not need to monitor the clock module as often as one needs to reset it, though in practice for accurate and definitive timings the clock drift needs to be measured at the beginning and end of every observing run.

The clock module can be set and read with ~1 second precision by typing the mtjohn commands **clockset** and **clockread** and then depressing the carriage-return key at the appropriate moment. (An aural indication of when to depress the carriage-return key comes from VNG/WWV/WWH, which are available from the small loudspeakers in the Boller & Chivens dome and McLellan data

roo[redacted] **clockset** functions like **prdate** plus **prtime**, except that **clockset** and **clockread** also display the value of the Clock Time Register, which, as described below, is needed by the VMS-based tape-reading software. The less-than-seconds registers of the clock module are neither set nor read with **clockset** and **clockread.**

For more accurate work the 'PETSET' box is provided. This box may be set to UT with much better than 1 second accuracy, either by using the National Radio time pips (via the detector box which at the time of writing is installed in Borealis) or by using the DSIR talking-clock service (via the portable detector box that can be connected to any Telecom jack point). The PETSET box counts minutes from its being set, and on every minute toggles various RS-232 signal levels in a DB-25 connector. This connector may be attached to any one of the four serial ports at the rear of the PM3000 computer. (In the McLellan data room it may be more convenient to attach the PETSET box by breaking into the extension cabling that goes to the dome command terminal. Use a gender bender at the point at which the RS-232 extension cable from the PM3000 connects to the data-room wall box.) The commands **petset_clockread** and **petset_clockset** respectively read and set the PM3000 clock module on the PETSET box minute tick, fractions of a second included. (Note that the millisecond value returned by **petset_clockread** ceases to be correct ~9 hours after the most recent set of the Interrupt Service Register.)

Observers are requested for preference to monitor the clock module during each observing run and to obtain appropriate corrections rather than to reset the clock module. The clock module should be reset only when it is deviating from UT by more than ~60 seconds. The graph below shows how the clock module performed at Mt John between 1989 October and 1990 November, where TICKS is the value of **$tdate** and UT-CCD is [Universal Time - clock module reading] (i.e. the clock module ran fast). **Observers should record details of all readings and resettings of the clock module in the 'CCD instrument log book'.**



Nine-track data tapes are read into the VAX/VMS system in Christchurch using the command **$ccd_to_vax.** The executable module invoked by this command opens a file ccd_clock_drift.dat in which the reading of the clock drift should be recorded in the following ASCII format:-

```
This file records the MJUO Photometrics clock drift
  Ticks     Approx UT date, time   UT-CCD     How determined          By whom
================================================================================
        0   1970-Jan-01 00:00:00     0.0
614999999   1989-Jun-28 01:19:59     0.0
615000000   1989-Jun-28 01:20:00    +34.        (Extrapolation)
   .
   .
   .
637909200   1990-Mar-20 05:00:00     -3.        From ACG's wristwatch ACG
638946240   1990-Apr-01 05:04:00     -7.        Petset from radio     WT
639014766   1990-Apr-02 00:06:06     -6.        Petset from radio     WT & ACG
639014820   1990-Apr-02 00:07:00      0.        Reset; Ptst fm radio  WT & ACG
639569243   1990-Apr-08 10:07:23     -3.        Petset fm DSIR phone  WT
   .
   .
   .
652078929   1990-Aug-31 05:02:09    -69.        Petset fm DSIR phone  WT
652095840   1990-Aug-31 09:44:00      0.        Reset. Ptst DSIR ph   WT
652337980   1990-Sep-03 04:59:40      0.83      Petset fm DSIR phone  ACG
653022605   1990-Sep-11 03:10:       -5.07                            ACG
   .
   .
   .
```

Only the 'Ticks' and 'UT-CCD' columns are actually used by **$ccd_to_vax** : the other columns are for greater human readability. The commands **$edccdcd, $edpccdcd** and **$edtccdcd** permit editing of ccd_clock_drift.dat, while **$edrccdcd** allows ccd_clock_drift.dat to be examined but not altered. (**$edrccdcd** is appropriate if the clock-drift file is being examined over a noisy line, such as via dial-up Pacnet access from Mt John.) The command **$updateccd** purges ccd_clock_drift.dat : an Access Control List ensures that only versions created by (i.e. belonging to) the particular user are purged.

Users may find the VAX/VMS command **$unixtime** useful : its purpose is similar to that of **pdt.** When a CCD data transfer tape is read with **$ccd_to_vax** the values in ccd_clock_drift.dat are used in the calculation of a corrected mean time of observation. This corrected mean is used in the calculation of airmass and julian day. If the time of observation is between two 'ticks' values in ccd_clock_drift.dat, a correction is linearly interpolated; otherwise, it is linearly extrapolated from the two most recent drift values.

For a definitive correction (i.e. one which will not alter through subsequent additions to the clock drift file), observers should ensure that ccd_clock_drift.dat includes a value of UT-CCD obtained subsequent to their most recent observation. When resetting the clock module, observers should bear in mind the VAX/VMS interpolation scheme. A **clockread** or **petset_clockread** should be performed immediately prior to the **clockset** or **petset_clockset.** Another **clockread** or **petset_clockread** should then be performed at some later stage to ensure that the large change

bet[redacted]n the **clockread** or **petset_clockread** and the **clockset** or **petset_clockset** is never used for extrapolating what would be an enormous clock correction. Values in the FITS header and the **hardcopy** printouts indicate the correction applied and whether it was interpolated or extrapolated.

The VAX/VMS command **$ccd_to_vax** displays the file ccd-clock-drift.dat to the user before proceeding to the tape read. This is to remind the user that the clock drift file should ideally be up to date before any new data tapes are read.

It is hoped that users will cooperate in monitoring the drift of the clock module and in entering values in ccd_clock_drift.dat.† **However, it must be stressed that it is the sole responsibility of the individual observer to monitor or set the clock module to the accuracy appropriate for the desired observations.** Observers are at the very least advised to check the clock module at the beginning and end of each observing run.

† Non-Christchurch users may find it safer and/or more convenient to e-mail values to w.tobin@csc.canterbury.ac.nz

University of Canterbury Department of Physics & Astronomy

Mt John University Observatory

Mt John Photometrics CCD System

Use and Performance Note
Number 8

FORTH
ACQUISITION SOFTWARE

W. Tobin

1991 May 28

These Notes are intended for guidance only: individual observers have the sole responsible for the integrity of their own data. Users of the CCD system are encouraged to summarize the performance that they obtain in a Note in this series. Contact Dr. W. Tobin to be allocated a series number.

FORTH ACQUISITION SOFTWARE

W. Tobin

1991 May 28

1 Introduction

The Mt John Photometrics CCD camera system is operated through its PM3000 computer, which is based on a Motorola 68020 microprocessor. The software for camera control, image acquisition, image storage, image display and other functions has been written in FORTH (and some assembler language). FORTH is an interpreted language devised in the 1970s at the National Radio Astronomy Observatory, Charlottesville, specifically for instrument control (Moore, C.H.:1974 *Astron. Astrophys. Suppl. Ser.***15**, 497-511).

The CCD system as delivered by Photometrics incorporates base-level FORTH software for CCD control. This system is described in the 'Photometrics 3000 Forth Manual'. Mt John extensions to this software have been written which considerably improve the ease and convenience of use of the CCD.

The principal advantage of FORTH is that it allows the observer easily to define personal observing words. The observer is not bound by the flow imposed by menu-driven software. The knowledge of FORTH required by the average observer is minimal: most observers will probably find that acquaintance with the **:** ⋯ **;** construction for defining new words is sufficient. For example, the following line typed on the command terminal:

: vword v_filter expose 99500 ms readout bell 1 -dark 3 flatfield sho ;

defines a new word **vword**. When executed by typing **vword** this new word sets the filter register to `V`, makes a 100-second exposure timed by the clock module (see Use and Performance Note No. 7), rings the terminal bell to alert the observer to the end of the exposure, subtracts the dark/offset frame stored in image cache 1 from the just-acquired exposure, multiplies the resulting frame by 10 000 and then divides it by the flatfield image stored in image cache 3, and finally displays the result on the RS170 video monitor(s).

More complicated structures such as loops and conditionals are available in FORTH : the user should consult one of the references suggested at the end of this section.

Observers' personal observing words can be typed in afresh at the start of each observing session. This may become tedious for regular users. In this case, they can be allocated a FORTH file in which their words are stored permanently. Consult Dr. W. Tobin about this possibility if interested.

FORTH is not case sensitive. Users may type FORTH words in upper and/or lower case, as desired. In the sections that follow upper case has sometimes been used for greater mnemonic value.

To load the base-level system the user should proceed as follows:

- Switch on the PM3000 computer, the terminal(s), the video monitor(s), the printer and any other pieces of equipment that may be relevant, such as the M4 9-track tape drive and the CE200 camera electronics unit.
- Press the RESET button on the front of the PM3000 chassis. It needs to be held in for one second to have effect.
- The system should respond as is indicated in `typewriter` font in what follows. Respond by typing on the terminal the commands shown in **bold**:

```
Heurikon Corporation
M10-Bug
Ver 1.8

>bw                                  Boot Forth kernel from the Winchester (hard disk)
IoForth ver.  2.09, Copyright '84 Io, Inc.  25Jul86
\25 load                                 Load Forth system and Photometrics software
Redef.: CODE
Redef.: ;CODE
Redef.: BASIC-FORTH
Photometrics CCD Camera System November 07, 1988
\lf mtjohn                                                  Load the Mt John extensions
Mt John utilities loading....
Redef.: ls
Redef.: qimages
   .
   .
   (Other redefinitions and information messages)
   .
   .
Mt John utilities loaded
\
```

- The \ prompt shows that the system is now awaiting commands from the user. If the user has a file of personal commands, now is the time to load it (e.g **lf acg**). Otherwise, the first command to issue would normally be **apon**.

Note that the Mt John extensions seize the first image cache as a work area, and in consequence Photometrics commands such as **seq** which require the entire image-cache area are unavailable. The Mt John extensions (and everything that has subsequently been added to the dictionary) can be 'unloaded' with **forget -mtjohn**.

The primary references to the FORTH that underlies the Photometrics system are:

Io Inc.: 1982 'IoForth Manual' Io Inc., Tucson.
Io Inc.: 1982 'IoForth Dictionary' Io Inc., Tucson.

These two volumes relate specifically to the FORTH system on the PM3000, but be warned that, as with so many computer manuals, not every detail of performance is correctly described. Copies of these manuals are stored in the bookshelf under the PM3000 enclosure. Users may also

find it useful to consult the listings of the Photometrics software and the Mt John extensions which are kept in a ring binder which is also stored in this bookshelf.

Other more general references to FORTH which the user may find useful include the following, but assumptions about word lengths (8-bits, 16-bits, etc.) and other details may be inappropriate for the PM3000 FORTH :

Brodie, L. & Forth, Inc.:1987 'Starting Forth' Prentice-Hall, Inc., Eaglewood Cliffs.

Kail, P.A.C.:1989 'Forth: a complete course in the Forth programming language' Kogan Paul, London.

Noble, J.:1989 'Scientific computation in Forth' *Computers in Physics* Sept/Oct 1989, 31-38.

Palmer, B.:1988 'Forth: The choice for scientific instruments' *Computers in Physics* Mar/Apr 1988, 54-61.

2 Mt John FORTH extensions – grouped by function

1. **PRINTER AND TERMINAL CONTROL.** An HDS 3200 terminal is attached close to the PM3000 computer and is the primary command terminal for program control. A Panasonic KX-P1081 dot-matrix serial printer is attached to this terminal's printer port so that a listing of each observing session can be made. When observing with the McLellan telescope it is also possible to issue commands from a second terminal located in the telescope dome.

   apon starts 'autoprinting' - i.e. a session listing will be made on the dot-matrix printer. *Users are strongly recommended to make a listing of every observing session, not only for their own use, but because of the information it provides for the elimination of software bugs or in the case of breakdowns.* Certain commands such as **caches** do not echo on the printer, even when **apon** has been selected. In these cases, a complimentary command such as **pr_caches** has been provided which *does* echo on the printer. The terminal screen is never automatically echoed to the printer when the terminal is in Tektronix mode (see **tekprint**).

   apoff stops the terminal screen being echoed to the dot-matrix printer.

   tek puts the terminal in Tektronix (graphics) mode.

   vt puts the terminal in VT220 (alphanumeric) mode.

   tekerase clears the screen when the command terminal is in Tektronix (graphics) mode.

   vterase clears the screen when the command terminal is in VT220 (alphanumeric) mode.

   tekprint copies the entire Tektronix-mode screen to the printer. In this way plots produced by the Photometrics switch word **tplot** and command words such as **hist**, **pcol**, **pcols** etc. can be entered into the observing session listing.

   vtprint copies the entire alphanumeric-mode screen to the printer.

   132_on puts the command terminal(s) when in alphanumeric mode into a column width of 132 characters.

   80_on puts the command terminal(s) when in alphanumeric mode into a column width of 80 characters.

   hds disables the second command terminal. This is appropriate if the second command terminal is not attached. It may also appropriate for certain commands which place the command terminal in Tektronix mode, such as **hist** after the **tplot** switch has been used. In Tektronix mode some cross talk between the two terminals can occur, resulting in corrupted output. Circumvent the problem with **hds**. The printer XON/XOFF flow control for extensive listings may also occasionally suffer when both terminals are active. Also try **hds** if problems are encountered with the mouse.

   both_term enables acceptance of commands from both terminals. The second terminal's keyboard buffer is only two characters long.

   reset_printer resets the printer (should it ever get blocked in an undesired mode).

   form_feed sends a form feed to the printer. (N.B. the user should ensure that the paper folds are appropriately positioned if it is wished to start a new page with this command.)

fprint filename lists the file **filename** on the command terminal, and, if **apon** has been selected, on the dot-matrix printer. One of the words **3print** or **6print** should be used before **fprint** to select either 3 or 6 blocks of the file per page of printer paper. It is probably prudent to invoke **hds** before **fprint** (see **hds**). Ensure also that the paper fanfolds are correctly positioned (see **form_feed**).

3print is a switch word for use before **fprint**. See **fprint**.

6print is a switch word for use before **fprint**. See **fprint**.

2. **SETTING THE IMAGE HEADER.** A 160-byte header is associated with each image stored in cache, on disk, or on tape. The header contains information as to CCD readout parameters, instrument used and its settings, time of acquisition, target identity, reductions performed, etc. These parameters are stored in the header at the time of image creation. Some are obtained by copying from registers that are set with the following words:

set_telescope informs the user of the options for setting the telescope register.

b&c sets the telescope register appropriately for the 0.6-metre Boller & Chivens reflecting telescope. Do not confuse with **b&cs**.

1f 8 sets the telescope register appropriately for the 1-metre McLellan telescope equipped with the secondary mirror and field-flattening optics for the f/7.7 cassegrain focus.

1f 13 sets the telescope register appropriately for the 1-metre McLellan telescope equipped with the secondary mirror for the f/13.5 cassegrain focus.

set_observer prompts for up to 4 ASCII characters that identify the observer(s).

target shows the string currently stored in the target name register and then prompts for a new string of up to 30 ASCII characters to replace it. The target name part of this string should not contain any blanks. The target string is stored left-justified in the comment field of the image header whenever an image is acquired with **n obs**, or **expose** and **readout**. It is also copied with other text into the comment field when commands such as **n lisse**, **n HeAr** etc. are used.

The Christchurch VAX-based tape reading software searches the file ccd_targets.dat to find the right ascension and declination of each target. The target names used with **target** should therefore be stored in ccd_targets.dat before data transfer tapes are read into the VAX system. Target names are delineated by blanks, and so must not contain any. Use constructions such as `RY_Sgr` or `cpd-61d455`. The identity adopted by the VAX software is that of the first target name identified in a left-to-right search of the comment field of the image header. The identification of target-name strings is case insensitive.

set_target is similar to **target**, but does not display the current target name string.

set_target_name is the same as **set_target**.

set_instrument informs the user of the options for setting the instrument register. When invoked, these options may show the current settings of the filter register and up to four other parameter registers, and ask if changed settings should be stored.

pentax sets the instrument register to indicate that images are being acquired through the Pentax 50 mm camera lens.

top_hat sets the instrument register to indicate that the CCD is being used for astronomical imagery with the 'Top-Hat' adapter.

b&c_spectrograph sets the instrument register to indicate that the CCD is being used for astronomical spectroscopy with the Boller & Chivens low-resolution spectrograph. Current values are then displayed for registers which hold the number of lines per millimetre of the grating, the grating angle (in form ±DD.MM), the real slit width in micron, and the focus setting of the collimator mirror (in thou). The user is given the option of changing these settings. The order-separating filter must be specified separately. Options are displayed to the user, and at the time of writing are **BG12**, **RG630**, **C371**, **quartz** and **no_filter**. The command **b&cs** is identical to **b&c_spectrograph**, but saves typing.

b&cs
is identical to **b&c_spectrograph**, but saves typing. Do not confuse with **b&c**.

echelle sets the instrument register to indicate that the CCD is being used for astronomical spectroscopy with the Mt John high-resolution échelle spectrograph. Current values are then displayed for registers which hold the cross grating name, the cross grating micrometer setting, the échelle tilt, and the slit width micrometer setting. The user is given the option of changing these settings.

photometer sets the instrument register to indicate that the CCD is being used for astronomical imaging photometry with the CCD photometer head and offset guider that at the time of writing is under construction. Since the photometer head will be controlled by the PM3000 computer it is anticipated that many additional FORTH words will be needed for photometer control.

tcomment allows the user to add a comment to the current image header after the target name string.

comment allows the user to respecify the entire 80-character comment field of the current image header, i.e. any target name is written over.

3. SET_ AND SHOW_ WORDS.

set_instrument informs the user of the options for setting the instrument register. When invoked, these options may show the current settings of the filter register and up to four other parameter registers, and ask if changed settings should be stored.

show_instrument displays on the command terminal(s) relevant parameters for the currently-selected instrument.

set_observer prompts for up to 4 ASCII characters that identify the observer(s).

show_observer displays on the command terminal(s) the 4 ASCII characters that identify the observer(s).

set_target prompts for a string of up to 30 ASCII characters to identify the target under observation. The target name part of this string should not contain any blanks. The target string is stored left-justified in the comment field of the image header whenever an image is acquired with **n obs**, or **expose** and **readout**. It is also copied with other text into

the comment field when commands such as **n lisse**, **n HeAr** etc. are used.

The Christchurch VAX-based tape reading software searches the file ccd_targets.dat to find the right ascension and declination of each target. The target names used with **target** should therefore be stored in ccd_targets.dat before data transfer tapes are read into the VAX system. Target names are delineated by blanks, and so must not contain any. Use constructions such as `RY_Sgr` or `cpd-61d455`. The identity adopted by the VAX software is that of the first target name identified in a left-to-right search of the comment field of the image header. The identification of target-name strings is case insensitive. The word **target** is very similar in function to **set_target**, but saves on typing.

set_target_name is identical to **set_target**.

show_target displays the target name.

show_target_name is identical to **show_target**.

set_telescope informs the user of the options for setting the telescope register.

show_telescope displays the contents of the telescope register.

show_header displays the header of the current image. This information is not echoed to the dot-matrix printer (use **pr_header**).

set_filter displays some of the available options for setting the filter register.

show_filter displays the current setting of the filter register.

4. **IMAGE ACQUISITION.** The image-acquisition commands provided by Photometrics have been redefined to be more useful. All the commands store additional material in the image header besides what is stored by the Photometrics software. Additional items recorded with the Mt John extensions include: telescope, observer initials and instrument and instrument settings. In addition, flags in the header indicate any reduction procedures applied, such as **-dark**. And finally, each image acquisition command that results in an image readout (other than **n dark** and **bias**) causes a bias image to be read out immediately afterwards. The mean signal level in the central 50×50 pixel area is calculated, and this offset+preflash level is stored in the image header and displayed to the user. The offset+preflash level is a relevant quantity, since it has been found to depend on the temperature of the CE200 electronics box (see Use and Performance Note No. 5: Temperature sensitivity of the CE200 electronics unit). The dark subtraction command **n -dark** warns the user if there is a significant mismatch between the offset levels of the two images being differenced.

See also special-purpose image acquisiton words discussed under '5. Photometry' and '6. Spectroscopy'.

n obs clears the CCD, preflashes it, opens the shutter and obtains an exposure lasting **n** deciseconds. The exposure is not timed by the clock module, but by some other clock, which runs $\sim 4\,\%$ fast (see Use and Performance Note No. 7: Time keeping on the Photometrics CCD system.) The time at which the exposure began is displayed so that the user can estimate when it will finish. (The PM3000 is occupied throughout the exposure.) The target name string is transferred to the comment area of the image header. Images acquired with **n obs** have the exposure start time and exposure dura-

tion set in the image header.

bias clears the CCD, preflashes it, and then immediately reads it out. The string `BIAS` is stored in the comment area of the image header.

n dark clears the CCD, preflashes it, waits **n** deciseconds, and then reads it out. The exposure is not timed by the clock module, but by some other clock, which runs $\sim 4\,\%$ fast (see Use and Performance Note No. 7: Time keeping on the Photometrics CCD system.) The time at which the dark exposure began is displayed so that the user can estimate when it will finish. (The PM3000 is occupied throughout the exposure.) The string `DARK` is stored in the comment area of the image header. Images acquired with **n dark** have the exposure start time and exposure duration set in the image header.

expose waits until the clock module ticks the second, clears the CCD, preflashes it, opens the shutter and begins an exposure. The time at which the exposure began is stored in a register and displayed to the user. The PM3000 is then available for further command entry.

readout waits until the clock module ticks the second, closes the shutter, and reads out the CCD. The exposure end time and the exposure duration is displayed to the user. Because of the waits for the clock module ticks, the exposure duration is an integral number of seconds, but the shutter will be open for slightly less time than this because of the time taken to clear the CCD and preflash it. (The preflash duration is set at 70 ms.) **Readout** also transfers the target name string to the comment area of the image header. Images acquired with **expose** and **readout** have the exposure start and end times set in the image header.

5. **PHOTOMETRY.** In an attempt to minimise confusion, the term 'flat field' will be used for calibration images acquired for the purpose of correcting for individual pixel sensitivity variations across the two-dimensional field of the CCD when used for imaging photomtery. The term 'smooth field' will be used for calibration images acquired in spectroscopy for the purpose of correcting for the high spatial frequency CCD sensitivity variations along the dispersion direction of a spectrogram.

   The target strings `DOME_FLAT` and `SKY_FLAT` are recognised by the VAX-based tape-reading software in Christchurch, and should be used to identify flat-field images (which would normally be acquired with **n obs**).

   External users with their own filters can use **read_ascii_parameter** to set the filter name register, but may prefer to define personal observing words analogous to **U_filter**, **B_filter**, etc. (see the FORTH listing of the Mt John extensions).

   See also '7. Image arithmetic'.

   top_hat sets the instrument register to indicate that the CCD is being used for astronomical imagery with the 'Top-Hat' adapter.

   photometer sets the instrument register to indicate that the CCD is being used for astronomical imaging photometry with the CCD photometer head and offset guider that at the time of writing is under construction. Since the photometer head will be controlled by the PM3000 computer it is anticipated that many additional FORTH words will be needed for photometer control.

U_filter sets the filter register to `U`

B_filter sets the filter register to `B`

V_filter sets the filter register to `V`

I_filter sets the filter register to `I`

No_filter sets the filter register to `None`

set_filter displays some of the available options for setting the filter register.

show_filter displays the current setting of the filter register.

filter_name read_ascii_parameter waits for the user to type up to 4 ASCII characters which it will store in the filter name register. Users wishing to use this sequence frequently may wish to redefine it as a personal observing word.

n flatfield multiplies the current image by 10 000 and divides it by the image stored in cache **n**. The user is warned if the filters associated with the two images differ, or if the image stored in cache **n** has not been normalised to a mean of 10 000 (see **normalise**). A flag `FLAT` is stored in the image header to record that the image has been flat fielded. The arithmetic is done in integer mode, so may be a source of additional noise at low signal levels.

6. **SPECTROSCOPY.** Special words have been written to facilitate acquisition of the numerous calibration frames required for astronomical spectroscopy.

b&c_spectrograph sets the instrument register to indicate that the CCD is being used for astronomical spectroscopy with the Boller & Chivens low-resolution spectrograph. Current values are then displayed for registers which hold the number of lines per millimetre of the grating, the grating angle (in form ±DD.MM), the real slit width in micron, and the focus setting of the collimator mirror (in thou). The user is given the option of changing these settings. The order-separating filter must be specified separately. Options are displayed to the user, and at the time of writing are **BG12**, **RG630**, **C371**, **quartz** and **no_filter**. The command **b&cs** is identical to **b&c_spectrograph**, but saves typing.

b&cs is identical to **b&c_spectrograph**, but saves typing. Do not confuse with **b&c**.

echelle sets the instrument register to indicate that the CCD is being used for astronomical spectroscopy with the Mt John high-resolution échelle spectrograph. Current values are then displayed for registers which hold the cross grating name, the cross grating micrometer setting, the échelle tilt, and the slit width micrometer setting. The user is given the option of changing these settings.

n lisse obtains a spectrograph smooth field image of **n** deciseconds duration.
The string `SMOOTH_FIELD` is written into the comment field of the image header; `for target_name` is added if the target name register has been set. The observer is resposible for ensuring that the spectrograph really is 'observing' the spectrograph smooth-field source.

n HeAr obtains a Boller & Chivens spectrograph wavelength calibration image of **n** deciseconds duration. The string `HeAr` is written into the comment field of the image header; `for target_name` is added if the target name register has been set. The observer is resposible for ensuring that the Boller & Chivens spectrograph re-

ally is 'observing' the helium-argon wavelength-calibration lamp.

n Th obtains an échelle spectrograph wavelength calibration image of **n** deciseconds duration. The string `Th_arc` is written into the comment field of the image header; `for target_name` is added if the target name register has been set. The observer is resposible for ensuring that the échelle spectrograph really is 'observing' the Thorium wavelength-calibration arc lamp.

n arc obtains a spectrograph wavelength calibration image of **n** deciseconds duration. The string `Arc` is written into the comment field of the image header; `for target_name` is added if the target name register has been set. The observer is resposible for ensuring that the spectrograph really is 'observing' a wavelength-calibration arc.

BG12 sets the filter register to `BG12`. This is used to indicate that a 1 mm piece of Schott BG12 glass has been used as the order-separating filter in the Boller & Chivens spectrograph.

C371 sets the filter register to `C371`. This is used to indicate that a 3 mm piece of Corning 3-71 glass has been used as the order-separating filter in the Boller & Chivens spectrograph.

RG630 sets the filter register to `RG63`. This is used to indicate that a 2 mm piece of Schott RG630 glass has been used as the order-separating filter in the Boller & Chivens spectrograph.

quartz sets the filter register to `Qrtz`. This is used to indicate that a block of quartz has been installed in the order-separating filter assembly in the Boller & Chivens spectrograph.

No_filter sets the filter register to `None`.

n smoothfield is designed for use with the Boller & Chivens spectrograph. It multiplies the current image by 10 000 and divides it by the image stored in cache **n**. The user is warned if the grating angles associated with the two images differ, or if the image stored in cache **n** has not been normalised to a mean of 10 000 (see **normalise**). A flag `SMTH` is stored in the image header to record that the image has been smooth fielded. The arithmetic is done in integer mode, so may be a source of additional noise at low signals.

7. IMAGE ARITHMETIC.

n cachecopy copies the image in cache **n** into the current image cache.

n -dark subtracts the image in cache **n** from the image in the current image cache. The user is warned if the image to be subtracted is not a dark image (i.e. one not containing `DARK` left-justified in its comment field), and is given the opportunity to abort the subtraction. The user is also warned and given the opportunity to abort execution if the offset levels of the two images differ by the equivalent of more than ~ 30 electrons. (In this case the user may wish to acquire a new dark/offset image.) A flag `-DRK` is set in the image header to record that the image has been dark subtracted.

n m c*/ integer multiplies each pixel in the current image by the integer **n** and then integer divides it by the integer **m**. The intermediate result can exceed the limits of the 16 bits of PM3000 FORTH integer variables.

median requests the cache numbers of three input images and one output image. The user is warned if the input images are not of the same

type e.g. different filters, or not all dark frames. The pixel-by-pixel median of the three input images is computed and stored in the output image. A flag `MNCL` is set in the header of the median image. **Median** is written in FORTH and executes relatively slowly, taking ~ 45 seconds for full-sized CCD frames. The *mean* of the offsets of the 3 input images is stored as the offset of the median image. Users should employ **normalise** as appropriate to ensure than the three input images have similar signal levels, otherwise **median** will just select the middle-intensity input image.

normalise gives the user the opportunity to abort execution if the current image has not been dark subtracted, and then rescales the image so that the mean value of all pixels (a 10-pixel wide border excluded) is 10 000. A flag `NORM` is set in the image header to record that the image has been normalised. Sets of flatfield and other calibration images should of course be **normalise**d before they are **median** clipped.

n flatfield multiplies the current image by 10 000 and divides it by the image stored in cache **n**. The user is warned if the filters associated with the two images differ, or if the image stored in cache **n** has not been normalised to a mean of 10 000 (see **normalise**). A flag `FLAT` is stored in the image header to record that the image has been flat fielded. The arithmetic is done in integer mode, so may be a source of additional noise at low signal levels.

n smoothfield is designed for use with the Boller & Chivens spectrograph. It multiplies the current image by 10 000 and divides it by the image stored in cache **n**. The user is warned if the grating angles associated with the two images differ, or if the image stored in cache **n** has not been normalised to a mean of 10 000 (see **normalise**). A flag `SMTH` is stored in the image header to record that the image has been smooth fielded. The arithmetic is done in integer mode, so may be a source of additional noise at low signals.

8. **WORDS THAT SUMMARIZE STORED IMAGES**.

caches summarizes information stored in the headers of the images in the image caches. The information displayed is more pertinent than that given by **qimages**. The information is not echoed to the dot-matrix printer.

pr_caches performes like **caches** except that the output is echoed to the dot-matrix printer if **apon** has been selected.

qimages performs as defined by Photometrics, but does not echo on the dot-matrix printer.

pr_qimages performs like **qimages** except that the output is echoed to the dot-matrix printer if **apon** has been selected.

9. **TAPE HANDLING.** Images are normally written to half-inch 9-track tape for transport and storage. Tapes are loaded by opening the M4 door, inserting the tape, closing the door, and then pressing LOAD and RESET. Tapes can be unloaded by pressing RESET and REWIND. A write ring must be in place if it is desired to write on a tape.

   In the event of a failure with the M4 tape drive, users can store images on appropriately-formatted 40 Mbyte data cassettes. It should be possible to reread these images and transfer them to

9-track tape once the M4 drive has been repaired. A number a formatted data cassettes are kept in the drawer in the CCD computer rack against the possibility of M4 failure. Immediately inform Dr. W. Tobin if it becomes necessary to use them.

It should be noted that the first tape-handling command issued often produces a SCSI error. The command will usually execute successfully if repeated.

This section lists all the words needed for tape handling (Photometrics included).

mttape is the switch word for selecting the M4 9-track tape drive. Loading the Mt John FORTH extensions invokes **mttape**.

hctape is the switch word for selecting the 40 Mbyte data cassette drive that is located at the front top right of the PM3000 enclosure.

newtape is a Photometrics word that initialises a 9-track tape. The first tape-controlling word used sometimes fails: often this is **newtape**. In this case, the word will normally work at the second attempt.

topen 'opens' the selected tape drive for access. It prompts for the tape or cassette identifier (e.g. T123 or AC05) which is subsequently printed out in the messages produced by **tw**, etc. It informs the user how many images are stored on the tape (according to the number stored in the first file on tape). *If this number is wrong, the user should desist and mount a new tape.*

tclose rewinds the tape (if appropriate) and if images have been written to the tape updates the tape's first file so that it contains the total number of images on the tape. *If a tape is written to and then unloaded before a* **tclose** *has been performed, it should not be used further. At the next* **topen** *the number in the first file will be wrong, and images will be overwritten. Desist and mount a fresh tape. The images will be accessible in Christchurch because the* VAX*-based software does not require that the number in the first file be correct.*

+twrite is a Photometrics software lock required before a tape or cassette can be written to.

-twrite is a Photometrics software lock preventing writing to tape or cassette.

tw writes the current image to the selected tape drive and displays an appropriate message. If the data cassette drive is selected it is necessary to type **n tw** where **n** is the position on cassette where the image is to be written.

n tr reads image **n** off the currently-mounted tape or cassette and stores it in the current image cache.

10. **CORRECTING A BAD IMAGE HEADER.** Image headers are created immediately after chip readout. If instrument or similar registers have been mis-set (or not set) it is possible to create a new, corrected header for the current image cache without having to reacquire the image, so long as this is done before any further images have been acquired. (An image and header once written to tape cannot be altered, but it is possible to make a second copy of the image with a corrected header, and to store them to tape too.)

    To correct a header, set the parameter registers correctly with the usual words such as **set_observer**, **V_filter**, **echelle**, etc., and then transfer them over to the current image cache header with **params_to_header**. The commands **read_ascii_parameter** and

read_real_parameter may occasionally prove useful. **Comment** can be used *at any time* to correct the 80-character comment field of an image. It is not easy to alter reduction flags, acquisition times, or CCD readout parameters.

show_header displays the header of the current image. This information is not echoed to the dot-matrix printer. The instrument parameters `param_1` etc. are displayed as both real and ASCII quantities: it is left to the user to interpret them appropriately.

pr_header displays the header of the current image. This information is echoed to the dot-matrix printer.

params_to_header copies values from various registers to the image header in the current image cache.

tcomment allows the user to add a comment to the current image header after the target name string.

comment allows the user to respecify the entire 80-character comment field of the current image header, i.e. any target name is written over.

address **read_ascii_parameter** waits for keyboard entry of an up to 4-character ASCII string and stores it beginning at location *address*. Use this procedure to correct ASCII parameter registers that have been improperly set. Register addresses that the user may wish to change can be placed on the stack by typing the following variable names:

- `filter_name`
- `param_1`
- `param_2`
- `param_3`
- `param_4`

Note that whether `param_1` etc. should be treated as ASCII or real parameters depends on which instrument is being used. The user should use **show_header** and the relevant instrument-setting command to determine what quantity is strored in each `param_` for the instrument in question, and whether it is a real or ASCII variable.

address **read_real_parameter** waits for keyboard entry of a real variable (integer or floating point) and stores it beginning at location *address*. Use this procedure to correct real parameter registers that have been improperly set. Register addresses that the user may wish to change can be placed on the stack by typing the following variable names:

- `param_1`
- `param_2`
- `param_3`
- `param_4`

Note that whether `param_1` etc. should be treated as ASCII or real parameters depends on which instrument is being used. The user should use **show_header** and the relevant instrument-setting command to determine what quantity is strored in each `param_` for the instrument in question, and whether it is a real or ASCII variable.

11. **WORDS FOR TIMEKEEPING.** (*See also* Use and Performance Note No. 6: Time keeping on the Photometrics CCD system).

petset_clockset checks that the user really wishes to reset the clock module, prompts for the new date and time, and sets the clock module to this time (fractions of a second included) when the PETSET box ticks the minute. The PETSET box may be plugged into any free RS-232 port on the PM3000.

petset_clockread reads the clock module (fractions of a second included) when the PETSET box ticks the minute. The PETSET box may be plugged into any free RS-232 port on the PM3000. The appropriate value of TICKS needed for the VAX file ccd_clock_drift.dat is also displayed.

clockset checks that the user really wishes to reset the clock module, prompts for the new date and time, and sets the clock module to this time (but not resetting the fractional parts of the second) when any key is pressed.

clockread reads the clock module immediately and displays the corresponding date and time. Fractional parts of a second are ignored. The appropriate value of TICKS needed for the VAX file ccd_clock_drift.dat is also displayed.

ut_to_ticks prompts for a date and time which it converts to the corresponding value of TICKS .

n pdt is a Photometrics word which displays the date and time that correspond to value **n** of TICKS .

?sec waits until the Interrupt Service Register ticks the second. This word may be useful in personal observing words if it is desired that an interval is an integral number of seconds. (N.B. **expose** and **readout** incorporate **?sec** to ensure that exposure times deriving from use of these words are an integral number of seconds.)

sync_on_rtc waits until the Clock Time Module ticks the second.

getclock is a Photometrics word which reads the clock module and resets the Clock Time and Interrupt Service Registers. Some users have been experiencing stalling of the Clock Time Register. When this occurs, users should see whether **getclock** or **sync_on_rtc getclock** restores the Clock Time Register.

12. **MISCELLANEOUS WORDS.** Users writing personal observing words should peruse the FORTH listing of the Mt John extensions where they will find many other useful words not described here.

n cgain sets the readout gain parameter to **n**. The electron-to-ADU gain factor is at present not completely understood, but use of **cgain** displays an approximate value. Also displayed is the change of signal level at which **-dark** displays a warning message.

n hunt repeatedly takes exposures of **n** deciseconds duration and displays them (via **qshow**) on the image display monitor(s).

full_frame resets the CCD readout setting to the whole chip, with no binning. This command should be used to repair the damage to the image caches that results if the observer uses **Ctrl-Z** to break out of an **n m focus** sequence.

n cachecopy copies the image in cache **n** into the current image cache.

magnitude asks the observer to use the box cursor and the video display monitor to select a star and a representative sky background area from the current image. The stellar sky-corrected signal is displayed both as ADU *counts* and as a magnitude $= -2.5\log_{10}(counts)$. (*See also* **set_box**.)

magdiff asks the observer to use the box cursor and the video display monitor to select two stars and a representative sky background area from the current image. The stellar sky-corrected signals

is displayed both as ADU *counts* and as a magnitude difference $= -2.5 \log_{10}(counts_1/counts_2)$. (*See also* **set_box**.)

nrows ncols set_box sets the box cursor size to **nrows** × **ncols**. It is then necessary to use the appropriate mouse button to display the box cursor on the video monitor(s).

( ) FORTH words that delineate a comment. Useful for entering annotations into the listing of an observing session.

Ctrl-Z is the Photometrics word to interrupt execution and return to the \ prompt.

3 Mt John FORTH extensions – listed alphabetically

n -dark subtracts the image in cache **n** from the image in the current image cache. The user is warned if the image to be subtracted is not a dark image (i.e. one not containing `DARK` left-justified in its comment field), and is given the opportunity to abort the subtraction. The user is also warned and given the opportunity to abort execution if the offset levels of the two images differ by the equivalent of more than $\sim$ 30 electrons. (In this case the user may wish to acquire a new dark/offset+preflash image.) A flag `-DRK` is set in the image header to record that the image has been dark subtracted.

-twrite is a Photometrics software lock preventing writing to tape or cassette.

+twrite is a Photometrics software lock required before a tape or cassette can be written to.

?sec waits until the Interrupt Service Register ticks the second. This word may be useful in personal observing words if it is desired that an interval is an integral number of seconds. (N.B. **expose** and **readout** incorporate **?sec** to ensure that exposure times deriving from use of these words are an integral number of seconds.)

( ) FORTH words that delineate a comment. Useful for entering annotations into the listing of an observing session.

3print is a switch word for use before **fprint**. See **fprint**.

6print is a switch word for use before **fprint**. See **fprint**.

80_on puts the command terminal(s) when in alphanumeric mode into a column width of 80 characters.

132_on puts the command terminal(s) when in alphanumeric mode into a column width of 132 characters.

1f 8 sets the telescope register appropriately for the 1-metre McLellan telescope equipped with the secondary mirror and field-flattening optics for the f/7.7 cassegrain focus.

1f 13 sets the telescope register appropriately for the 1-metre McLellan telescope equipped with the secondary mirror for the f/13.5 cassegrain focus.

apoff stops the terminal screen being echoed to the dot-matrix printer.

apon starts 'autoprinting' - i.e. a session listing will be made on the dot-matrix printer. Certain commands such as **caches** do not echo on the printer, even when **apon** has been selected. The terminal screen is never automatically echoed to the printer when the terminal is in Tektronix mode (see **tekprint**). **Apon** *should be the first command issued for all observing sessions.*

n arc obtains a spectrograph wavelength calibration image of **n** deciseconds duration. The string `Arc` is written into the comment field of the image header; `for target_name` is added if the target name register has been set. The observer is resposible for ensuring that the spectrograph really is 'observing' a wavelength-calibration arc.

b&c sets the telescope register appropriately for the 0.6-metre Boller & Chivens reflecting telescope. Do not confuse with **b&cs**.

b&cs is identical to **b&c_spectrograph**, but saves typing. Do not confuse with **b&c**.

b&c_spectrograph sets the instrument register to indicate that the CCD is being used for astronomical spectroscopy with

the Boller & Chivens low-resolution spectrograph. Current values are then displayed for registers which hold the number of lines per millimetre of the grating, the grating angle (in form ±DD.MM), the real slit width in micron, and the focus setting of the collimator mirror (in thou). The user is given the option of changing these settings. The order-separating filter must be specified separately. Options are displayed to the user, and at the time of writing are **BG12**, **RG630**, **C371**, **quartz** and **no_filter**. The command **b&cs** is identical to **b&c_spectrograph**, but saves typing.

B_filter sets the filter register to `B`

BG12 sets the filter register to `BG12`. This is used to indicate that a 1 mm piece of Schott BG12 glass has been used as the order-separating filter in the Boller & Chivens spectrograph.

bias clears the CCD, preflashes it, and then immediately reads it out. The string `BIAS` is stored in the comment area of the image header.

both_term enables acceptance of commands from both terminals. The second terminal's keyboard buffer is only two characters long.

C371 sets the filter register to `C371`. This is used to indicate that a 3 mm piece of Corning 3-71 glass has been used as the order-separating filter in the Boller & Chivens spectrograph.

n m c*/ integer multiplies each pixel in the current image by the integer **n** and then integer divides it by the integer **m**. The intermediate result can exceed the limits of the 16 bits of PM3000 FORTH integer variables.

n cachecopy copies the image in cache **n** into the current image cache.

caches summarizes information stored in the headers of the images in the image caches. The information displayed is more pertinent than that given by **qimages**. The information is not echoed to the dot-matrix printer.

n cgain sets the readout gain parameter to **n**. The electron-to-ADU gain factor is at present not completely understood, but use of **cgain** displays an approximate value. Also displayed is the change of signal level at which **-dark** displays a warning message.

clockread reads the clock module immediately and displays the corresponding date and time. Fractional parts of a second are ignored. The appropriate value of TICKS needed for the VAX file ccd_clock_drift.dat is also displayed.

clockset checks that the user really wishes to reset the clock module, prompts for the new date and time, and sets the clock module to this time (but not resetting the fractional parts of the second) when any key is pressed.

comment allows the user to respecify the entire 80-character comment field of the current image header, i.e. any target name is written over.

n dark clears the CCD, preflashes it, waits **n** deciseconds, and then reads it out. The exposure is not timed by the clock module, but by some other clock, which runs $\sim 4\,\%$ fast (see Use and Performance Note No. 7: Time keeping on the Photometrics CCD system.) The time at which the dark exposure began is displayed so that the user can estimate when it will finish. (The PM3000 is occupied throughout the exposure.) The string `DARK` is stored in the comment area of the image header. Images acquired with **n dark** have the exposure start time and exposure duration set in the image header.

n -dark subtracts the image in cache **n** from the image in the current image cache. The user is warned if the image to be subtracted is not a dark image (i.e. one not containing `DARK` left-justified in its comment field), and is given the opportunity to abort the subtraction. The user is also warned and given the opportunity to abort execution if the offset levels of the two images differ by the equivalent of more than $\sim$ 30 electrons. (In this case the user may wish to acquire a new dark/offset+preflash image.) A flag `-DRK` is set in the image header to record that the image has been dark subtracted.

echelle sets the instrument register to indicate that the CCD is being used for astronomical spectroscopy with the Mt John high-resolution échelle spectrograph. Current values are then displayed for registers which hold the cross grating name, the cross grating micrometer setting, the échelle tilt, and the slit width micrometer setting. The user is given the option of changing these settings.

expose waits until the clock module ticks the second, clears the CCD, preflashes it, opens the shutter and begins an exposure. The time at which the exposure began is stored in a register and displayed to the user. The PM3000 is then available for further command entry.

n flatfield multiplies the current image by 10 000 and divides it by the image stored in cache **n**. The user is warned if the filters associated with the two images differ, or if the image stored in cache **n** has not been normalised to a mean of 10 000 (see **normalise**). A flag `FLAT` is stored in the image header to record that the image has been flat fielded. The arithmetic is done in integer mode, so may be a source of additional noise at low signal levels.

form_feed sends a form feed to the printer. (N.B. the user should ensure that the paper folds are appropriately positioned if it is wished to start a new page with this command.)

fprint filename lists the file **filename** on the command terminal, and, if **apon** has been selected, on the dot-matrix printer. One of the words **3print** or **6print** should be used before **fprint** to select either 3 or 6 blocks of the file per page of printer paper. It is probably prudent to invoke **hds** before **fprint** (see **hds**). Ensure also that the paper fanfolds are correctly positioned (see **form_feed**).

full_frame resets the CCD readout setting to the whole chip, with no binning. This command should be used to repair the damage to the image caches that results if the observer uses **Ctrl-Z** to break out of an **n m focus** sequence.

getclock is a Photometrics word which reads the clock module and resets the Clock Time and Interrupt Service Registers. Some users have been experiencing stalling of the Clock Time Register. When this occurs, users should see whether **getclock** or **sync_on_rtc getclock** restores the Clock Time Register.

hctape is the switch word for selecting the 40 Mbyte data cassette drive that is located at the front top right of the PM3000 enclosure.

hds disables the second command terminal. This is appropriate if the second command terminal is not attached. It may also appropriate for certain commands which place the command terminal in Tektronix mode, such as **hist** after the **tplot** switch has been used. In Tektronix mode some cross talk between the two terminals can occur, resulting in corrupted output. Circumvent the problem with **hds**. The printer XON/XOFF flow control for extensive listings may also occasionally suffer when both terminals are

active. Also try **hds** if problems are encountered with the mouse.

n HeAr obtains a Boller & Chivens spectrograph wavelength calibration image of **n** deciseconds duration. The string `HeAr` is written into the comment field of the image header; `for target_name` is added if the target name register has been set. The observer is resposible for ensuring that the Boller & Chivens spectrograph really is 'observing' the helium-argon wavelength-calibration lamp.

n hunt repeatedly takes exposures of **n** deciseconds duration and displays them (via **qshow**) on the image display monitor(s).

I_filter sets the filter register to `I`

n lisse obtains a spectrograph smooth field image of **n** deciseconds duration. The string `SMOOTH_FIELD` is written into the comment field of the image header; `for target_name` is added if the target name register has been set. The observer is resposible for ensuring that the spectrograph really is 'observing' the spectrograph smooth-field source.

magdiff asks the observer to use the box cursor and the video display monitor to select two stars and a representative sky background area from the current image. The stellar sky-corrected signals is displayed both as ADU *counts* and as a magnitude difference $= -2.5 \log_{10}(counts_1/counts_2)$. (*See also* **set_box**.)

magnitude asks the observer to use the box cursor and the video display monitor to select a star and a representative sky background area from the current image. The stellar sky-corrected signal is displayed both as ADU *counts* and as a magnitude $= -2.5 \log_{10}(counts)$. (*See also* **set_box**.)

median requests the cache numbers of three input images and one output image. The user is warned if the input images are not of the same type e.g. different filters, or not all dark frames. The pixel-by-pixel median of the three input images is computed and stored in the output image. A flag `MNCL` is set in the header of the median image. **Median** is written in FORTH and executes relatively slowly, taking $\sim$ 45 seconds for full-sized CCD frames. The *mean* of the offsets of the 3 input images is stored as the offset of the median image. Users should employ **normalise** as appropriate to ensure than the three input images have similar signal levels, otherwise **median** will just select the middle-intensity input image.

mttape is the switch word for selecting the M4 9-track tape drive. Loading the Mt John FORTH extensions invokes **mttape**.

newtape is a Photometrics word that initialises a 9-track tape. The first tape-controlling word used sometimes fails: often this is **newtape**. In this case, the word will normally work at the second attempt.

No_filter sets the filter register to `None`

normalise gives the user the opportunity to abort execution if the current image has not been dark subtracted, and then rescales the image so that the mean value of all pixels (a 10-pixel wide border excluded) is 10 000. A flag `NORM` is set in the image header to record that the image has been normalised. Sets of flat-field and other calibration images should of course be **normalise**d before they are **median** clipped.

n obs clears the CCD, preflashes it, opens the shutter and obtains an exposure lasting **n** deciseconds. The exposure is not timed by the clock module, but by some other clock, which runs $\sim 4\,\%$ fast (see Use and Performance Note No. 7: Time keeping on

the Photometrics CCD system.) The time at which the exposure began is displayed so that the user can estimate when it will finish. (The PM3000 is occupied throughout the exposure.) The target name string is transferred to the comment area of the image header. Images acquired with **n obs** have the exposure start time and exposure duration set in the image header.

params_to_header copies values from various registers to the image header in the current image cache.

pentax sets the instrument register to indicate that images are being acquired through the Pentax 50 mm camera lens.

petset_clockread reads the clock module (fractions of a second included) when the PETSET box ticks the minute. The PETSET box may be plugged into any free RS-232 port on the PM3000. The appropriate value of TICKS needed for the VAX file ccd_clock_drift.dat is also displayed.

petset_clockset checks that the user really wishes to reset the clock module, prompts for the new date and time, and sets the clock module to this time (fractions of a second included) when the PETSET box ticks the minute. The PETSET box may be plugged into any free RS-232 port on the PM3000.

n pdt is a Photometrics word which displays the date and time that correspond to value **n** of TICKS .

photometer sets the instrument register to indicate that the CCD is being used for astronomical imaging photometry with the CCD photometer head and offset guider that at the time of writing is under construction. Since the photometer head will be controlled by the PM3000 computer it is anticipated that many additional FORTH words will be needed for photometer control.

pr_caches performes like **caches** except that the output is echoed to the dot-matrix printer if **apon** has been selected.

pr_header displays the header of the current image. This information is echoed to the dot-matrix printer.

pr_qimages performs like **qimages** except that the output is echoed to the dot-matrix printer if **apon** has been selected.

qimages performs as defined by Photometrics, but does not echo on the dot-matrix printer.

quartz sets the filter register to `Qrtz`. This is used to indicate that a block of quartz has been installed in the order-separating filter assembly in the Boller & Chivens spectrograph.

address **read_ascii_parameter** waits for keyboard entry of an up to 4-character ASCII string and stores it beginning at location *address*. Use this procedure to correct ASCII parameter registers that have been improperly set. Register addresses that the user may wish to change can be placed on the stack by typing the following variable names:

- `filter_name`
- `param_1`
- `param_2`
- `param_3`
- `param_4`

Note that whether `param_1` etc. should be treated as ASCII or real parameters depends on which instrument is being used. The user should use **show_header** and the relevant instrument-setting command to determine what quantity is strored in each `param_` for the instrument in question, and whether it is a real or ASCII variable.

address **read_real_parameter** waits for keyboard entry of a real variable (integer or

floating point) and stores it beginning at location *address*. Use this procedure to correct real parameter registers that have been improperly set. Register addresses that the user may wish to change can be placed on the stack by typing the following variable names:

- `param_1`
- `param_2`
- `param_3`
- `param_4`

Note that whether `param_1` etc. should be treated as ASCII or real parameters depends on which instrument is being used. The user should use **show_header** and the relevant instrument-setting command to determine what quantity is strored in each `param_` for the instrument in question, and whether it is a real or ASCII variable.

readout waits until the clock module ticks the second, closes the shutter, and reads out the CCD. The exposure end time and the exposure duration is displayed to the user. Because of the waits for the clock module ticks, the exposure duration is an integral number of seconds, but the shutter will be open for slightly less time than this because of the time taken to clear the CCD and preflash it. (The preflash duration is set at 70 ms.) **Readout** also transfers the target name string to the comment area of the image header. Images acquired with **expose** and **readout** have the exposure start and end times set in the image header.

reset_printer resets the printer (should it ever get blocked in an undesired mode).

RG630 sets the filter register to `RG63`. This is used to indicate that a 2 mm piece of Schott RG630 glass has been used as the order-separating filter in the Boller & Chivens spectrograph.

?sec waits until the Interrupt Service Register ticks the second. This word may be useful in personal observing words if it is desired that an interval is an integral number of seconds. (N.B. **expose** and **readout** incorporate **?sec** to ensure that exposure times deriving from use of these words are an integral number of seconds.)

nrows ncols set_box sets the box cursor size to **nrows** × **ncols**. It is then necessary to use the appropriate mouse button to display the box cursor on the video monitor(s).

set_filter displays some of the available options for setting the filter register.

set_instrument informs the user of the options for setting the instrument register. When invoked, these options may show the current settings of the filter register and up to four other parameter registers, and ask if changed settings should be stored.

set_observer prompts for up to 4 ASCII characters that identify the observer(s).

set_target is similar to **target**, but does not display the current target name string.

set_target_name is the same as **set_target**.

set_telescope informs the user of the options for setting the telescope register.

show_filter displays the current setting of the filter register.

show_header displays the header of the current image. This information is not echoed to the dot-matrix printer (use **pr_header**).

show_instrument displays on the command terminal(s) relevant parameters for the currently-selected instrument.

show_observer displays on the command terminal(s) the 4 ASCII characters that identify the observer(s).

show_target displays the target name.

show_target_name is identical to **show_target**.

show_telescope displays the contents of the telescope register.

n smoothfield is designed for use with the Boller & Chivens spectrograph. It multiplies the current image by 10 000 and divides it by the image stored in cache **n**. The user is warned if the grating angles associated with the two images differ, or if the image stored in cache **n** has not been normalised to a mean of 10 000 (see **normalise**). A flag `SMTH` is stored in the image header to record that the image has been smooth fielded. The arithmetic is done in integer mode, so may be a source of additional noise at low signals.

sync_on_rtc waits until the Clock Time Module ticks the second.

target shows the string currently stored in the target name register and then prompts for a new string of up to 30 ASCII characters to replace it. The target name part of this string should not contain any blanks. The target string is stored left-justified in the comment field of the image header whenever an image is acquired with **n obs**, or **expose** and **readout**. It is also copied with other text into the comment field when commands such as **n lisse**, **n HeAr** etc. are used.

tclose rewinds the tape (if appropriate) and if images have been written to the tape updates the tape's first file so that it contains the total number of images on the tape. *If a tape is written to and then unloaded before a* **tclose** *has been performed, it should not be used further. At the next* **topen** *the number in the first file will be wrong, and images will be overwritten. Desist and mount a fresh tape. The images will be accessible in Christchurch because the* VAX*-based software does not require that the number in the first file is correct.*

tcomment allows the user to add a comment to the current image header after the target name string.

tek puts the terminal in Tektronix (graphics) mode.

tekerase clears the screen when the command terminal is in Tektronix (graphics) mode.

tekprint copies the entire Tektronix-mode screen to the printer. In this way plots produced by the Photometrics switch word **tplot** and command words such as **hist**, **pcol**, **pcols** etc. can be entered into the observing session listing.

n Th obtains an échelle spectrograph wavelength calibration image of **n** deciseconds duration. The string `Th_arc` is written into the comment field of the image header; `for target_name` is added if the target name register has been set. The observer is resposible for ensuring that the échelle spectrograph really is 'observing' the Thorium wavelength-calibration arc lamp.

top_hat sets the instrument register to indicate that the CCD is being used for astronomical imagery with the 'Top-Hat' adapter.

topen 'opens' the selected tape drive for access. It prompts for the tape or cassette identifier (e.g. T123 or AC05) which is subsequently printed out in the messages produced by **tw**, etc. It informs the user how many images are stored on the tape (according to the number stored in the first file on tape). *If this number is wrong, the user should desist and mount a new tape.*

n tr reads image **n** off the currently-mounted tape or cassette and stores it in the current image cache.

tw writes the current image to the selected tape drive and displays an appropriate message. If the data cassette drive is selected it is necessary to type **n tw** where **n** is the position on cassette where the image is to be written.

-twrite is a Photometrics software lock preventing writing to tape or cassette.

+twrite is a Photometrics software lock required before a tape or cassette can be written to.

U_filter sets the filter register to `U`

ut_to_ticks prompts for a date and time which it converts to the corresponding value of TICKS .

V_filter sets the filter register to `V`

vt puts the terminal in VT220 (alphanumeric) mode.

vterase clears the screen when the command terminal is in VT220 (alphanumeric) mode.

vtprint copies the entire alphanumeric-mode screen to the printer.

Ctrl-Z is the Photometrics word to interrupt execution and return to the \ prompt.

University of Canterbury Department of Physics & Astronomy

Mt John University Observatory

Mt John Photometrics CCD System

Use and Performance Note
Number 9

PROBLEMS OF CCD
FLAT FIELDING

W. Tobin

1992 August 28

These Notes are intended for guidance only: individual observers have the sole responsible for the integrity of their own data. Users of the CCD system are encouraged to summarize the performance that they obtain in a Note in this series. Contact Dr. W. Tobin to be allocated a series number.

PROBLEMS OF CCD FLAT FIELDING

This *Use and Performance Note* is the text prepared for publication[1] of an oral presentation made at IAU Colloquium 136 'Stellar Photometry' at Trinity College Dublin, 1992 August 4-7. In it the experience gained at the Boller & Chivens telescope has been merged with that from the McLellan telescope to bring out fundamental points about flat fielding. It is hoped that the circulation of this document now will be useful to observers, even though the appropriate procedures for high-accuracy flat fielding are still unclear for both the Boller & Chivens and McLellan telescopes.

[1] I. Elliott, editor; Cambridge University Press, publisher.

Problems of CCD flat fielding

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Abstract

CCD flat fielding using an illuminated dome screen is discussed. Rings of reduced response caused by dust specks on the cryostat entrance window indicate the required uniformity of screen illumination but may not divide satisfactorily because of telescope flexure. Illumination colour is important for shorter-wavelength, broad-band filters. Flat fields can be distorted significantly by light scattered off telescope baffles. Special precautions are needed for uv flat fielding. The Mt John TH 7882 CDA chip is slightly sensitive to polarisation. Dome flat-fielding accuracy of 0.3% would seem achievable.

1. Introduction

The system sensitivity is nonuniform across an astronomical CCD image because of factors such as interpixel sensivity variations intrinsic to the chip, shadows cast by dust specks on the cryostat window and other optical surfaces, filter inhomogeneities, streaky or bubbly optical cements, and telescope vignetting. A flat-field (sensitivity-map) image attempts to represent the combined effect of these variations. Before photometry can be extracted from CCD science images they must be corrected to uniform sensitivity through division by the appropriate flat-field image. (The process of flat fielding cannot of course correct for any intrapixel sensitivity variation.)

Correct flat fielding is crucial for the observer who seeks precise and accurate photometry. This paper discusses aspects of flat-fielding attempts made using the Photometrics Ltd. cryogenic CCD system which has been in use at the Mt John University Observatory (MJUO), Lake Tekapo, since late 1989 (e.g. Tobin, 1991). Because MJUO is a private facility, it has been possible to conduct more tests than is practical for a visiting observer at an international facility. While I have yet to achieve the ~0.3% flat-fielding accuracy desirable for my scientific programme (photometry of eclipsing binaries in the Magellanic Clouds), I hope my experience so far will provide useful guidance to others, especially those at smaller observatories. The reader should also study the articles by Djorkovski (1984), Djorkovski & Dickinson (1989) and Stetson (1989), and Chapter 5 of the book by Buil (1991).

To obtain a flat-field map it is only necessary to image a uniform, extended source. The twilight sky may be a suitable source for the small fields of view of many CCDs, but twilight flats are difficult to obtain because the sky must be unambiguously clear

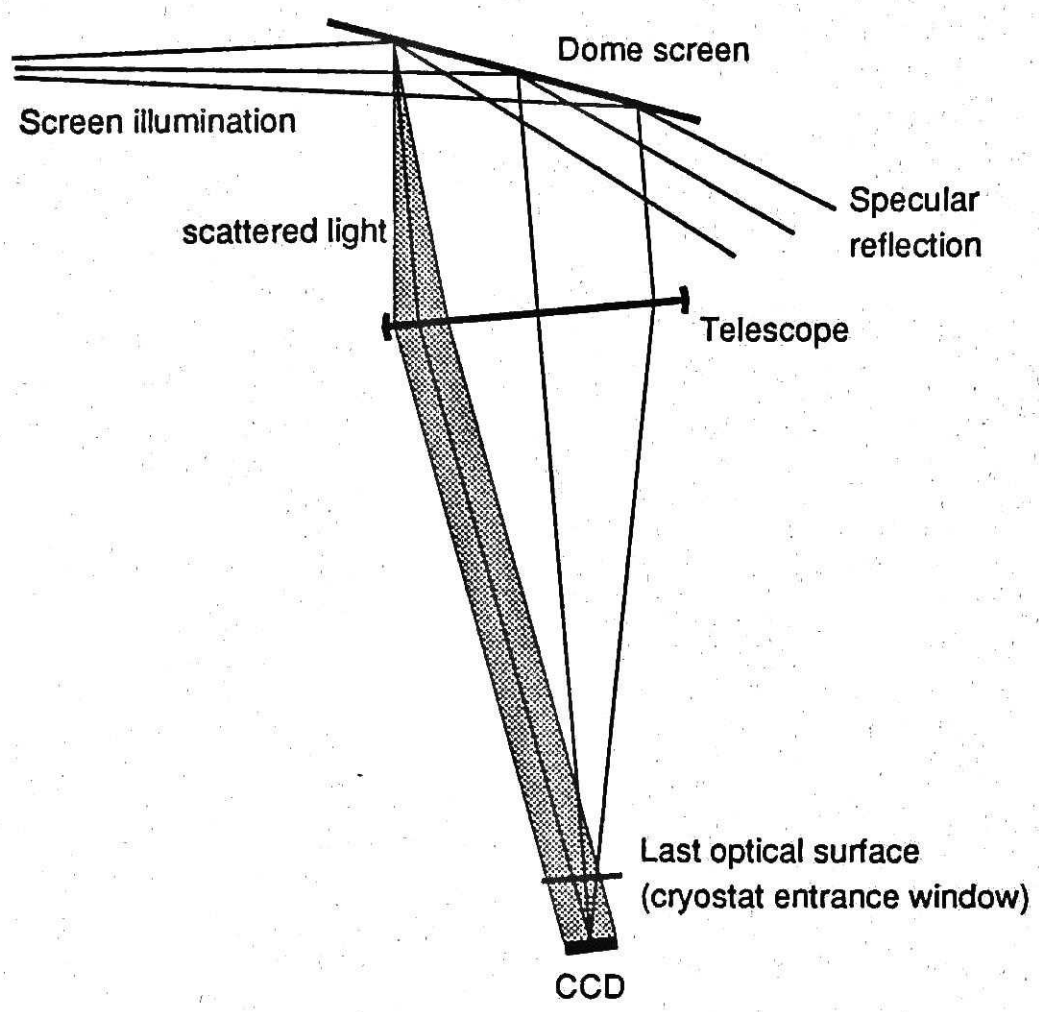

Figure 1 Schema of dome flat fielding. Each element of the screen illuminates the whole CCD, and each point of the CCD is illuminated by all elements of the screen.

and the signal strengths are appropriate for only a few minutes. Another, easier option is to use an illuminated screen within the dome: with the telescope focused at infinity, the claim is that the screen is so far out of focus that the telescope focal-plane illumination is nevertheless uniform.

At MJUO resident technician-observers do much of the variable-star observing. They cannot routinely be asked to extend their working night by the 1–2 hours needed to obtain sky flats (nor can clear twilight be assumed in New Zealand). On a nightly basis dome flats must be used at MJUO, so this paper concentrates on the question of dome flatting.

The tests reported here have been made with either the 0.61-m or the 1-m cassegrain telescopes at MJUO. The CCD is an overcoated 384×576-pixel Thomson TH 7882 CDA chip. On both telescopes its field of view is ~3.8×5.8 arcmin.

2. Dome flat fielding.

Can dome flatting be satisfactory? I think so, if properly arranged. Figure 1 sketches an arrangement. So long as one avoids angles at which the dome screen scattering function is changing rapidly (i.e. close to specular reflection) each elemental area of

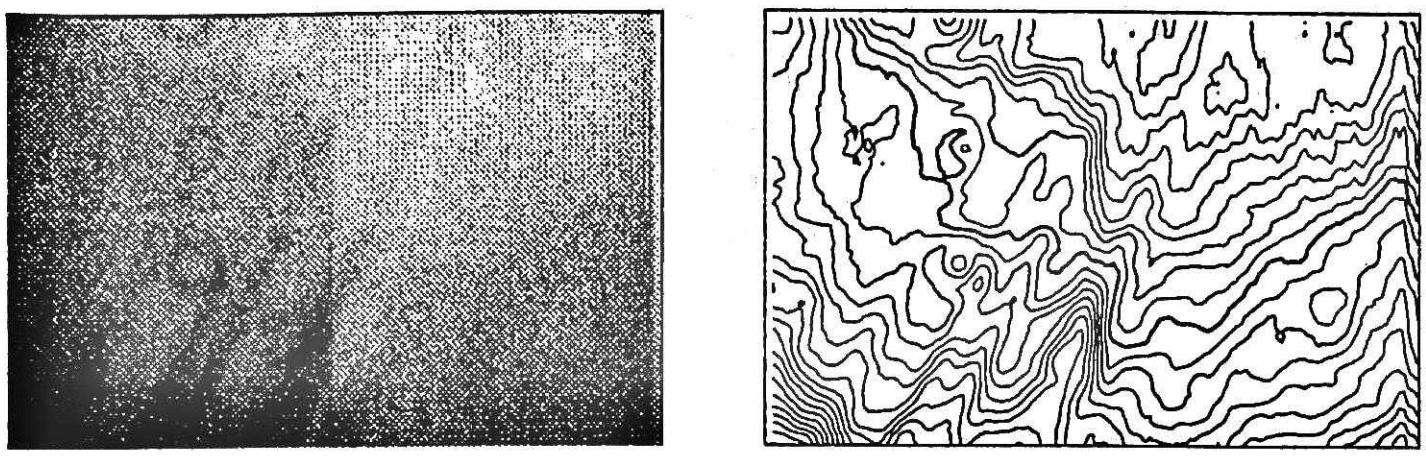

Figure 2 A MJUO V flat field represented *left* as a positive intensity-coded image and *right* in smoothed form as a contour map in which the heavy line represents the mean and the contour spacing is 0.5%. The r.m.s. variation of the flat field is 3.1% with a range of ~12%. In U, B and I the r.m.s. variations are respectively 3.6%, 3.5% and 2.5%.

the dome screen provides uniform illumination within the few arcminute spread of the ray directions which the telescope focuses to differing points on the CCD. The chip is thus uniformly illuminated (and its sensitivity variations correctly mapped) whatever the illumination pattern of the dome screen.

The uniformity of the screen illumination is however important for mapping the throughput variations caused by optical elements in front of the detector. The most obvious of these variations are rings of reduced response resulting from the occultation of the hollow core of the telescope beam by dust specks on the cryostat entrance window. Three examples are clearly seen in the sample MJUO flat field shown in Figure 2, which also shows sensitivity variations on all spatial scales. If the telescope beam is not uniformly filled because the screen is unevenly illuminated, the shadow ring is modulated and differs in intensity from that caused by a star. At MJUO these dust shadow rings depress the level of the flat field by ~3%, and this furnishes an indication of how uniform the scattered light from the dome screen must be. For 0.3% flat fielding the scattered light across the board must be uniform to ~0.3%/3% or ~10%. This can probably be checked with a light meter.

The relative insensitivity of MJUO dome flats to the details of the screen illumination is illustrated in Figure 3 which presents a ratio image in which a dome flat obtained with only *half* the screen illuminated has been divided by a dome flat obtained with a fully-illuminated screen. This severe modulation of the illumination generally only affects the flat field at the ~4% level. These variations principally derive from the glue that holds together the individual glasses in the filter some 50 mm in front of the CCD chip. The dust rings, being caused closer to the chip, are more severely affected and show more obviously the effect of the half-illuminated beam.

So long as the telescope is properly focused at infinity MJUO dome flats seem reproducible at the ~1% level irrespective of telescope orientation and small differences of screen illumination (e.g. illuminating lamp to east *vs.* lamp to west). However,

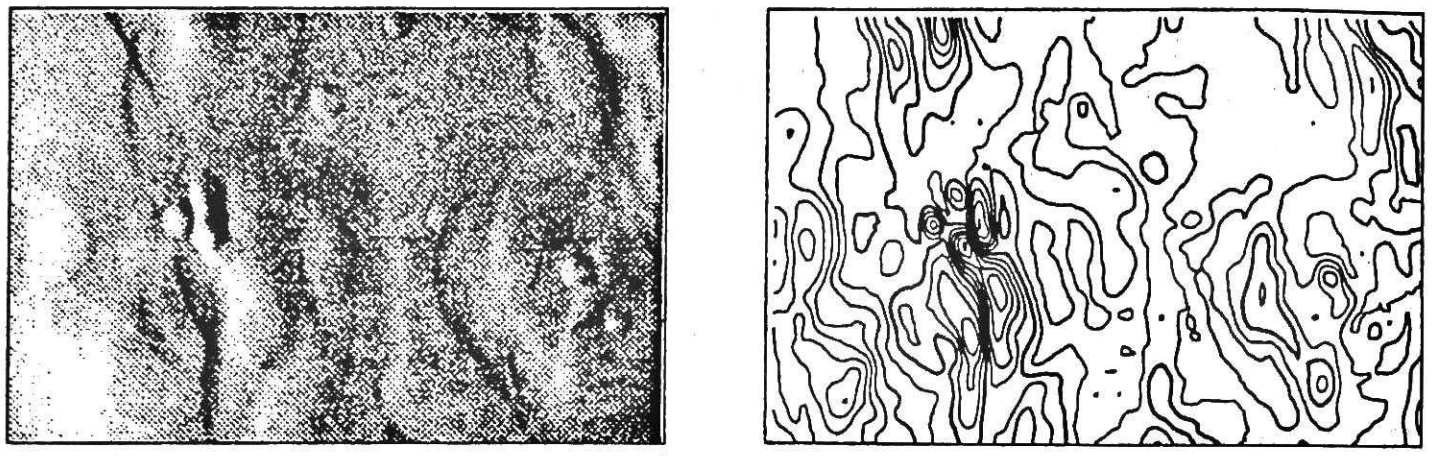

Figure 3 Ratio of two MJUO B flat fields. One was obtained with the dome screen illuminated in the normal way, the other with only half the screen illuminated. The ratio image is presented in the same two ways as in Figure 2.

because of flexure, the position of the dust rings on the chip varies with telescope orientation. For the best photometry dust rings should not impinge upon target stars.

Sky flats in B, V and I obtained from the dusk sky were compared with dome flats. The high spatial frequency variations agree very well, but the (sky flat/dome flat) ratios show large-scale systematic effects in all three bandpasses at the 1.0-1.5% level (Figure 4 gives an example). The filter bandpasses are weighted differently by the red illumination of the dome flats and the blue illumination of the sky flats. To investigate whether this could be the cause of the (sky/dome) differences, dome flats were obtained with the regular $UBVI$ filters, and then with cut-on or cut-off filters which bisected the $UBVI$ bandpasses placed in front of the screen-illuminating lamp. Linear combinations of the full and bisected $UBVI$ responses were made which more-or-less matched the responses to sky illumination, and corresponding synthetic (sky flat/dome flat) ratios were calculated. These show systematic differences of $\sim$1.5% in U, $\sim$1% in B, $\sim$0.5% in V and $\sim$0.1% in I. Figure 4 presents the results for B. The predicted (sky/dome) variation is sufficient to explain the observed (sky/dome) variation in B, but not in I (with V an intermediate case). Conversely, colour effects are likely to be important in the shorter-wavelength broad-band filters at the $\sim$0.5% level in V, increasing to $\sim$1.5% in U. Appropriate colour-balance filters are desirable to match the dome screen illumination to the colour of the stars being observed for short-wavelength, broad bands.

With dome and sky flats agreeing at the $\sim$1% level one might think that MJUO flat-field images are flat at this level. To check this, observations were made of two E-region standards which are $\sim$1 arcmin apart on the sky. The magnitude difference between the stars varied in a reproducible way by $\sim$4% depending on their location on the chip. Despite their similarity, the dome and sky flats are warped.

I believe the cause of this systematic error is scattered light. The telescope baffles prevent sky light from reaching the CCD chip directly, but as Figure 5 shows, considerable light is scattered off the inside of the primary mirror chimney baffle. The

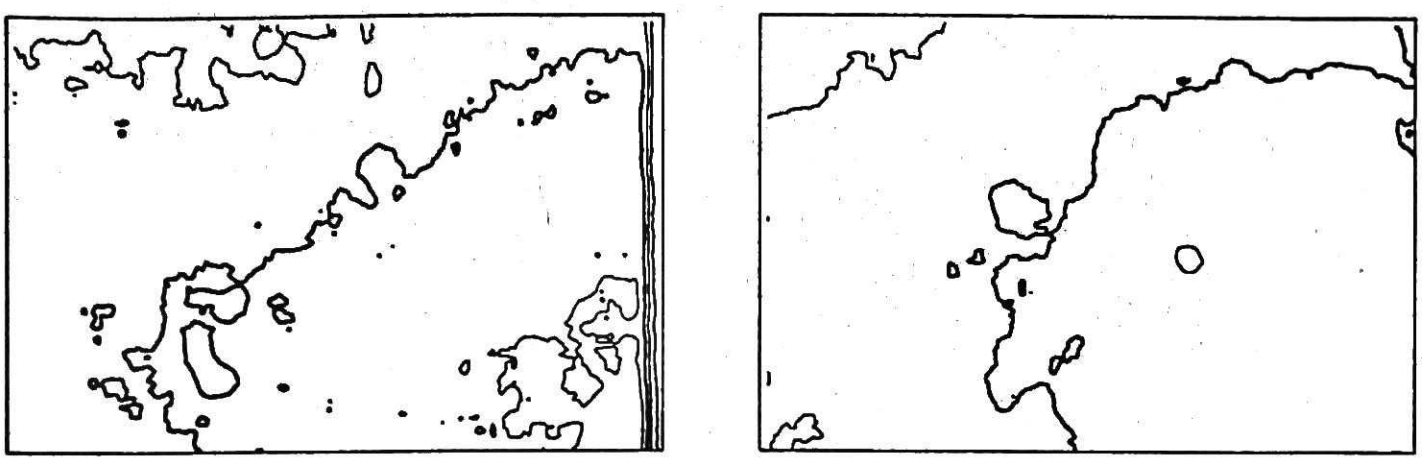

Figure 4 Contour plots of smoothed B (sky flat/dome flat) ratios (0.5% contour intervals). *Left* observed ratio, *right* model ratio synthesized from dome flats obtained with full and bisected bandpasses. The plots are very similar.

dome and sky flats agree because both derive from an extended source (the sky or the rectangular dome screen and reflective pale green dome interior), but both are wrong. Support for this explanation comes from dome flats obtained after the dome screen had been painted down with black paint to the size of the telescope beam. These flats are curved by several percent compared to earlier dome flats.

Annuli, which are very effective at curtailing scattered light, will now be installed in the baffles. Non-flatness of dome and sky flats can probably better be tested using not a pair of stars but observations of an extended open cluster taken at various different chip positionings. Pairwise magnitude differences can then be fitted to a 2D polynomial to check for and to model any remaining curvature of the flat field images, as suggested by Djorgovski (1984).

With the understanding of flat-fielding now obtained, I believe that the prospects are good for achieving the desired 0.3% flat-fielding accuracy.

3. Screens and lamps for dome flat fielding

Until recently slide projectors were used to illuminate rectangular screens of white-plasticized wood composite. In future I wish to extend observations to Strömgren u, and for this the spectral reflectance of the plasticization has been checked since many modern white materials contain 'optical brighteners'. These fluorescent dyes absorb from 300-400 nm and re-emit at longer wavelengths. The reflectance of the MJUO board drops by ~50% from 420 nm to 380 nm, which may cause colour-balance problems not so much for uv filters as for B and Strömgren v. Teflon sheet would seem a possibly more suitable screen material.

A uv-rich lamp is required to illuminate the screen. Mercury lamps show strong emission lines. Deuterium lamps are spectrally smooth and very blue from 300–400 nm, but are intrinsically faint. Xenon lamps have good and smooth uv output but necessitate precautions against explosion, ozone—and sunburn. Because of its safety, simplicity, low light spill, filter slots, easy availability and low cost a 1200 W theatrical

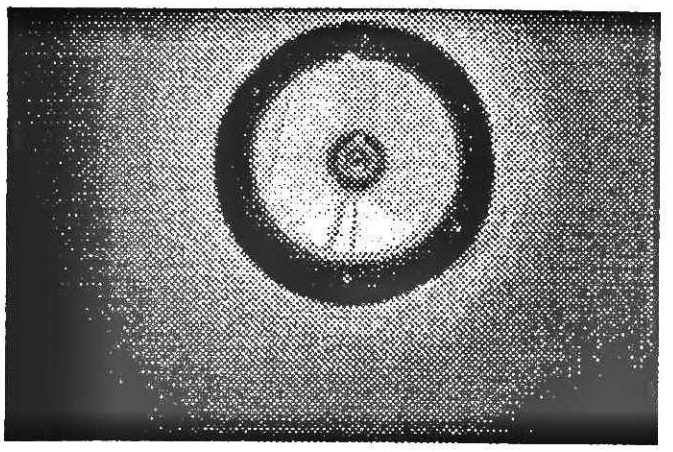

Figure 5 Scattered light in the chimney baffle of the MJUO 0.61-m Boller & Chivens cassegrain reflector. This image was acquired by placing a 50-mm camera lens in front of the CCD. The scattered light in the image is 11% of the light in the beam.

spotlight with mains-operated quartz-halide bulb has now been purchased for MJUO dome flat illumination. Its glass fresnel lens has been removed and a tube collimator installed to restrict its beam to the dome screen (rings within this tube dramatically tightened the beam). Using this spotlight, a dome flat with 0.5% statistical noise can be obtained in U in 40 s, and, it is estimated, in u in 4 min. For colour balancing or attenuation theatrical filters are readily available and can stand proximity to a 1200 W bulb. Further, filter sample books now include spectrophotometric tracings (though only to ~700 nm). The 1200 W spotlight is far too bright for red and ir flat fielding, so a 5 W lamp is under construction for this.

4. Polarization sensitivity

An attempt has been made to check the commonly-made assertion that CCDs are insensitive to polarization. Polaroid sheet was placed in a 1-m diameter rotatable holder located between the telescope and the dome screen. Dome flats obtained at different angles of polarization were compared for U, B and V. (Polaroid sheet is ineffective at I.) For a 90° rotation of the plane of polarization there is evidence of pixel-to-pixel sensitivity variations of at least 0.7%, but less than 3%.

Acknowledgments:

I thank Stephen Duncan, Murray Forbes and John Pritchard for assistance with various aspects of this work.

References:

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Mt John University Observatory

Mt John Photometrics CCD System

Use and Performance Note
Number 10

GAIN, NOISE AND RELATED CHARACTERISTICS OF THE MT JOHN PHOTOMETRICS CCD SYSTEM

W. Tobin

1992 November 10

These Notes are intended for guidance only: individual observers have the sole responsible for the integrity of their own data. Users of the CCD system are encouraged to summarize the performance that they obtain in a Note in this series. Contact Dr. W. Tobin to be allocated a series number.

GAIN, NOISE AND RELATED CHARACTERISTICS OF THE MT JOHN PHOTOMETRICS CCD SYSTEM

W. Tobin

1992 November 10

The gain, noise and related characteristics of the Mt John CCD system have been investigated. The results of this work have been published by Tobin, W., (1992) *Southern Stars* **34,** No. 8 421-429. This text is reproduced as an appendix to this *Use & Performance Note* for ease of reference, to update the references and to correct some minor printing errors introduced in *Southern Stars.*

Individual users can run the FORTH software that was developed for gain and noise determination in order to monitor the stability of the system gain and noise or for such other investigations as they judge pertinent. The procedure is entirely self-contained—no external test lamps are needed because the necessary test signals are generated by exposing on the the CCD system's illuminated flash ring for appropriate intervals. The principles underlying the gain and noise determination are described in the appendix, which should be read before proceeding further.

Only a 32×32-pixel region of the CCD is used for the gain and noise determination. However a 102×102-pixel region is actually read out so that the first several rows and columns can be discarded. This is because they are usually visibly corrupted in some way by the readout process. The pixels can actually be 'superpixels' if on-chip binning is selected. The user is responsible for ensuring that the 102×102-(super)pixel region lies within the chip boundaries. Exposure times are set automatically and span the range of ADU (Analogue-to-Digital Unit) values.

To run the software proceed as follows. The system output is shown in `typewriter` font. User input is shown in **bold**:

1. Switch on, boot the FORTH kernel, load the FORTH system and Photometrics software as described in *Use & Performance Note No. 8.*

2. Load the Mt John extensions with:
   \lf mtjohn

3. Set the desired value of `cgain`. E.g.:
   \0 cgain *for cgain=0*
   \100 cgain *for cgain=100*

4. Adjust the paper in the printer and invoke autoprinting with
   \apon

5. Invoke the gain and noise routine. The user is prompted for various parameters. Sample responses are shown:
   \determine_gain
   `Over-ride default test format?  175 135 102 102 1 1`
   `(yes/no?)`**y**
   The values `175 135 102 102 1 1` are the chip set-up values given by the Photometrics `format` command, i.e. column offset, row offset, number of columns, number of rows, column binning, row binning. A user response **n** accepts these default values, i.e.

- position of the 32×32-pixel region centered at column 226 (=175+102/2) and row 186 (=135+102/2)
- 1×1 binning.

Fig. 1 in the appendix illustrates the default positioning of the 32×32-pixel region on a part of the chip where the sensitivity is fairly uniform. If the user gives the response **y** (as shown) s/he is prompted further. For eaxample:

`Input col-offset` **282** *for column offset = 282 (=384-102) (the maximum permissible)*
`row-offset` **474** *for row offset = 474 (=576-102) (the maximum permissible)*
`col-binning` **1** *for single-pixel column binning*
`row-binning` **1** *for single-pixel column binning*

The sample output below shows typical numbers for the default position and cgain=100.

```
================================================================================
GAIN & READ-OUT NOISE DETERMINATION   6May92 13:54:42  UTC
cgain = 100  32x32 central pixels used in format    175 135 102 102 1 1
Trial of 10700  ms flash to determine exposure times ( 8415.9, 91.15)
```

Based on the value of `cgain` *and the known approximate gain behaviour of the CCD system a trial 10.7s exposure on the flash ring is made in order to determine the actual response and appropriate exposure times. The mean level of the central 32×32 central pixels of the image is found to be 8415.9 ADU and the r.m.s. is 91.15 ADU.*

```
Images with 0  ms flash -- individual means, root mean squares
(  376.4,  6.36)  (  369.2,  2.36)  (  368.7,  2.35)  (  368.4,  2.39)
```

A series of four images is acquired without illuminating the flash ring. After each image is read out it is displayed on the video monitor so the user can inspect it for glitches. The numbers in parentheses are the mean and r.m.s. values of the central 32×32 pixels of each image. The purpose of reading out these images is to allow the chip to 'cool down' after the preceeding bright exposure. The necessity of this is indicated by the higher mean and r.m.s. values associated with the first image.

```
Images with 0  ms flash -- individual means, root mean squares
(  368.3,  2.39)  (  368.2,  2.31)  (  368.2,  2.25)  (  368.2,  2.31)
Intercomparison: mean= 367.74, rms=   1.69, variance=   2.85
Adopted zero-exposure signal =   367.74
```

A further series of four zero-exposure images is acquired. The mean mean value of the central 32×32 pixels of the last three images is 367.74 ADU. The mean individual-pixel r.m.s. [=(variance)$^{\frac{1}{2}}$] derived by intercomparison of the same pixel in each of the last three images is 1.69 ADU. This value is of course lower than the r.m.s. values derived from each image singly, which are higher because of the extra spread caused by the differing sensitivities of each pixel. The value 367.74 will be subtracted from all future exposures to yield the quantity S (see appendix).

```
Images with 2  ms flash -- individual means, root mean squares
(  368.5,  2.39)  (  369.1,  2.37)  (  369.1,  2.40)  (  369.2,  2.33)
Intercomparison: mean= 368.75, rms=   1.87, variance=   3.49, Signal=    1.01
Images with 2  ms flash -- individual means, root mean squares
(  369.2,  2.42)  (  369.0,  2.34)  (  369.0,  2.44)  (  369.0,  2.33)
Intercomparison: mean= 368.62, rms=   1.81, variance=   3.29, Signal=    0.88
```

```
Images with 3  ms flash -- individual means, root mean squares
(  370.2,  2.51)  (  369.9,  2.45)  (  369.9,  2.43)  (  369.8,  2.45)
Intercomparison: mean= 369.47, rms=   1.91, variance=   3.66, Signal=    1.73
   .
   .
   .
Images with 12715  ms flash -- individual means, root mean squares
(10031.1,107.20)  (10042.1,105.66)  (10046.9,106.47)  (10047.6,106.85)
Intercomparison: mean=10063.70, rms= 52.90, variance=2798.58, Signal= 9695.96
Images with 19032  ms flash -- individual means, root mean squares
(14878.1,155.04)  (14891.3,153.83)  (14894.8,156.10)  (14896.8,154.18)
Intercomparison: mean=14929.22, rms=  65.80, variance=4329.78, Signal=14561.48
```

Images are acquired at 25 signal levels. The quantities $S =$`Signal` *and* $\sigma^2 =$`variance` *are those that will be fitted to Eqn. 2 of the appendix. The signal levels are roughly equally spaced in* $\log_{10} S$*. For regions of the chip where the sensitivity is markedly non-uniform the difference between the individual-image r.m.s. values and the intercomparison r.m.s. values will be even more marked. Acquisition of the 25 signal levels and priniting of the analysis takes* $\sim$*15 min. at* `0 cgain` *and* $\sim$*9 min. at* `100 cgain`*.*

`gaincore gaincore gaincore gaincore` *Four iterations of the Marquardt algorithm*

```
Convergence!!!
alpha:
  7.84573E+03  1.39306E+01  5.86016E+05
  1.39306E+01  3.51583E-01  2.10750E+02
  5.86016E+05  2.10750E+02  4.62116E+09
covar:
  6.23458E-03 -2.46562E-01 -7.79371E-07
 -2.46562E-01  1.25953E+01  3.06925E-05
 -7.79371E-07  3.06925E-05  3.13829E-10
correlation matrix:
  1.00000E-00 -8.79871E-01 -5.57178E-01
 -8.79871E-01  1.00000E-00  4.88182E-01
 -5.57178E-01  4.88182E-01  1.00000E-00
a:
  2.35090E-01  7.56032E-00  4.65232E-06
chi-squared:
  7.27956E-02
```

Quantities relating to the Marquardt algorithm and Gauss-Jordan elimination. See Press et al.*, (1986) Chapters 2 & 14.*

```
  FLASH     X=        Y=      log10X    log10Y    logeY    logeYfit    loge
DURATION  SIGNAL   VARIANCE                                          (Y/Yfit)
   (ms)    (ADU)   (ADU**2)
      2.    1.01      3.49    0.0023    0.5428    1.2499    1.2224    0.0275
      2.    0.88      3.29   -0.0539    0.5166    1.1895    1.2139   -0.0244
      3.    1.73      3.66    0.2379    0.5640    1.2986    1.2713    0.0273
    .
    .
```

```
    .
    .
  12715. 9695.96   2798.58    3.9866    3.4469    7.9369    7.9084    0.0285
  19032.14561.48   4329.78    4.1632    3.6365    8.3733    8.3923   -0.0190
```

The experimental data and fitted values and deviations are tabulated. The user should particularly check the `loge(Y/Yfit)` *[=* $\log_e(S/S_{fit})$*] column: any wild values indicate that the fit is biased and of reduced reliability. Fig. 2 in the appendix illustrates the quality of typical fits.*

```
  GAIN      INVERSE BASE-LEVEL CURVATURE
              GAIN    NOISE
(ADU/e-)   (e-/ADU)    (e-)
 0.2351       4.25     7.56    4.652E-06
+/-
 0.0043       0.08     0.19    9.559E-07
   r.m.s.logeY/Yfit   r.m.s.log10Y/Yfit
      (1 point)          (1 point)
        0.0540             0.0234
================================================================================
```

The finally-determined gain, inverse gain and base-level noise are calculated. The errors are internally derived from the r.m.s. values of $\log_e(Y/Y_{fit})$*, and not from considerations of the number of electrons detected.*

6. Deactivate the printer:
   \apoff

APPENDIX

Southern Stars **34,** No.8 421-429 (1992).

Gain, noise and related characteristics of the Mt John Photometrics CCD system

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Abstract

Software has been implemented on the Mt John CCD system for the automatic determination of its gain and noise properties. The gain can be selected by the observer and the system can be operated at inverse gains of only a few electrons per Analogue-to-Digital Unit. The system readout noise is ∼7 electrons. Images are subject to peak-to-peak 50 Hz mains pickup during readout of ∼9 electrons. At the highest signal levels there is 10-22 % more noise than can be accounted for by photon noise alone. Binning bias is sometimes apparent in the two lowest-order bits of the analogue-to-digital converter. The chip detects ∼9 cosmic ray events min^{-1}.

1. INTRODUCTION

The Mt John PM3000 CCD system was acquired from Photometrics Ltd. of Tucson in late 1988, and was installed at Mt John approximately one year later. The detector is a Thomson TH7882 CDA chip comprising 384×576 pixels, each of which is 23μm square. The chip has been overcoated with a fluorescent dye, Metachrome II, for blue and ultraviolet response. The detector is mounted behind the quartz window in an evacuated 'CH210' cryostat and in order to reduce thermal currents and their associated noise is cooled with liquid nitrogen to ~ 160 K. A mechanical shutter mounted in front of the cryostat window is opened to admit light during exposures. A 'flash ring' of 8 green LEDs is sandwiched between the shutter and the cryostat window. The flash ring is normally illuminated for 70 ms before the shutter is opened and an exposure begins. This flash deposits ∼300 electrons in each CCD pixel in order to minimise the reduced efficiency of charge transfer that can occur at very low signal levels. Signals from the chip are amplified and then converted to binary numbers by an Analogue-to-Digital Converter (ADC) in the nearby 'CE200' electronics box . The system computer is based on the Motorola 68020 chip and besides manipulating images, also controls image acquisition and image display on a video monitor. It is programmed in the FORTH instrument-control language (Moore, 1974; Palmer, 1988). Extensive additional FORTH programming has been undertaken to make the system easy and convenient for the observer to use. Images are recorded on $\frac{1}{2}$-inch 9-track magnetic tape at 1600 bpi. Fuller details of the system have been published elsewhere (Tobin 1991a, 1991b).

The CCD is a powerful device because of its high sensitivity and low noise, and is proving popular with observers at Mt John. Already two M.Sc. theses have been completed using it (Wadsworth, 1991; West, 1991), four Ph.D. projects are underway (at the University of Canterbury and the Victoria University Wellington) and it has attracted three sabbatical visitors to Christchurch (from Carter Observatory, from the University of Tasmania, and from the University of Northern Arizona). Additionally, the CCD has provided material for several non-thesis student projects, and CCD observations have been supplied to astronomers in France and the UK. The first results from the CCD system are now beginning to appear in the international refereed literature (West *et al.,* 1992; Watson *et al.,* 1992).

Gain and noise are crucial properties of any detector system, and these and other characteristics of the Mt John CCD system are discussed in this paper. In this context, the gain or transfer factor, G, is defined as the number of Analogue-to-Digital Units (ADUs) produced by the system's ADC per electronic charge detected. For the p-type substrate of the TH7882 chip, the gain units are thus ADU/e$^-$. Readers should be aware that the inverse gain, $Q = G^{-1}$, is also commonly used, and is itself sometimes referred to as 'the gain'. Gain should not be confused with sensitivity or quantum efficiency, which relate to the probability that an incoming photon produces a captured charge in the CCD substrate. Photometrics estimate that the overcoated TH 7882 has a quantum efficiency of ∼20 % from 300-400 nm, rising to a peak of ∼40 % at 650 nm, and declining to ∼25 % at 830 nm, ∼7 % at 950 nm and ∼0 % at 1.05 μm. The quantum efficiency at a particular wavelength is, however, not the same for every pixel, but varies by up to ∼5 % from its mean value. This is illustrated in Fig. 1, which represents the response to 14 s of light from the LED flash ring. The variation of response is mostly due to the variation of the sensitivity across the chip; some of the low spatial frequency variation derives from non-uniformity of the flash-ring illumination. Fig. 1 also illustrates the excellent cosmetic quality of the Mt John chip.

The gain of the Mt John system is, within limits, user-selectable via a software parameter `cgain`. The correct choice of `cgain` is crucial to the success of an observational programme, and its selection requires considerable care. A low gain will permit a large signal to be accumulated in a single exposure without exceeding the 14-bit limit of the ADC. However, low gain will also result in a large truncation or digitisation noise in weak signals such as sky backgrounds in imaging photometry and continuum levels in spectroscopy of emission nebulae. Digitisation noise is reduced at higher gain, but at the price of smaller dynamic range. The choice of gain is also a factor affecting the accuracy of flat-

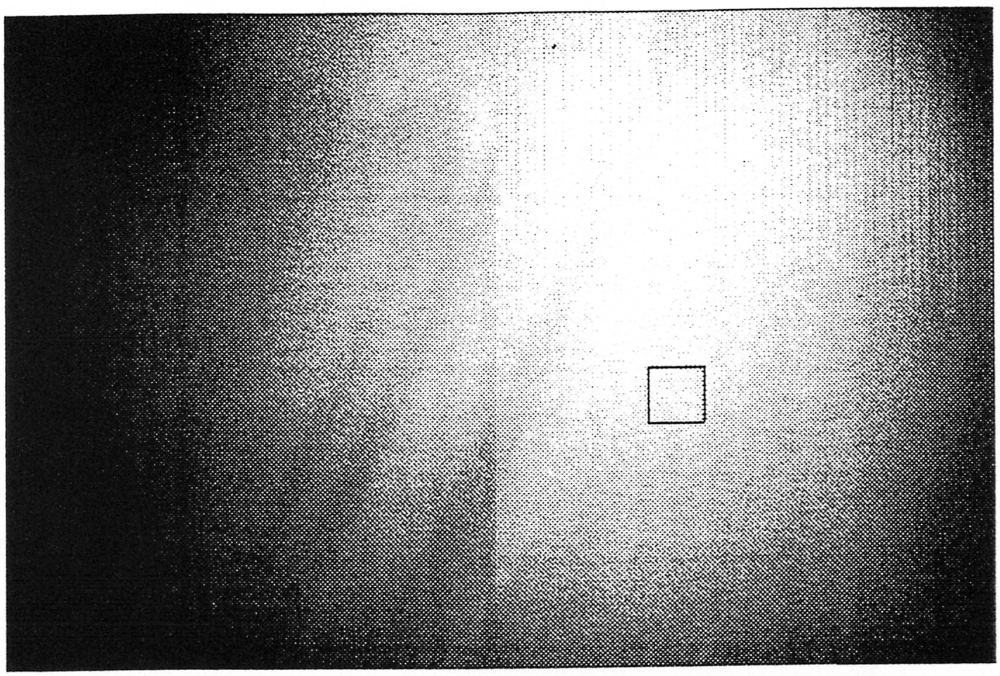

Figure 1: The response of the Mt John Photometrics PM3000 CCD system to 14 s of flash-ring illumination, illustrating the variation of sensitivity across the chip. The readout point is at upper right. The excellent cosmetic quality of the chip should be noted. The black square indicates the 32×32 pixel default region used for gain and noise determination.

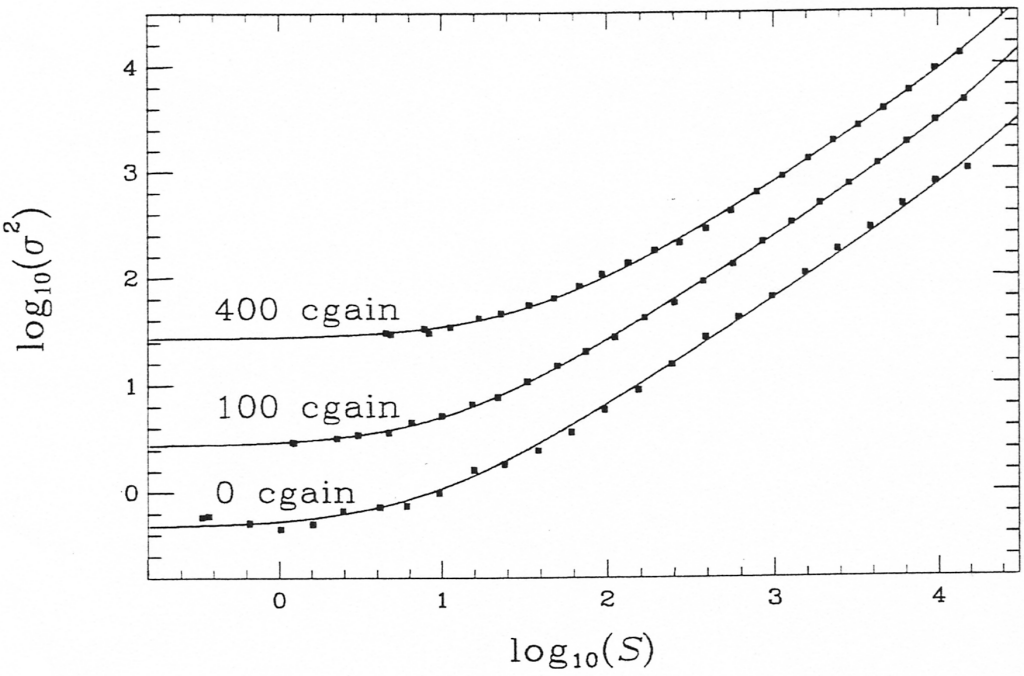

Figure 2: Variance diagrams for the Mt John CCD system for three different values of the software parameter `cgain`.

field (sensitivity-map) calibration images that are used to correct images for the CCD sensitivity variations. If a high gain is selected, it may be necessary to add several sensitivity maps in order to obtain adequately small individual-pixel statistical noise. If low gain is used, it may become necessary to perform field-flattening divisions at the observer's home institution, using real arithmetic, rather than during the observing session, because at low ADU levels significant truncation errors can be introduced by the PM3000's integer image arithmetic.

An expanding number of privately-circulated 'Use and Performance Notes' (listed below) detail the use and performance of the Mt John CCD system, but for two reasons it has been thought worthwhile to to give wider circulation via *Southern Stars* to the system's gain, noise and related properties. First, for prospective users in New Zealand and worldwide, these properties give an indication of the performance to be expected and are essential for pre-observation planning. Second, a number of similar Photometrics systems are in operation overseas, and intercomparison of the performance of these systems is helpful in ensuring the optimum operation of each instrument. Such systems include those at the University of Toronto Southern Observatory, Las Campanas (McCall *et al.,* 1989), the Vainu Bappu Observatory, Kavelur (Mayya, 1991; Prabhu *et al.,* 1992) and the Uttar Pradesh State Observatory, Naini Tal.

2. GAIN AND NOISE

In simple theory, the noise in a CCD signal is taken to comprise two components: (i) a constant read-out noise, R_e (in electrons), which derives from properties of the chip and amplifier, and (ii) the noise in the signal. The signal is presumed to be a Poisson process, i.e. the variance of its noise is equal to the number of electronic charges detected. The two noise components are independent and add quadratically. It is then easy to show that the noise, σ (in ADU), associated with any signal, S (in ADU), is given by

$$\sigma^2 = G^2 R_e^2 + GS \tag{1}$$

If several images are obtained at a particular exposure level S, they can be intercompared to derive σ, and then by obtaining a series of S–σ^2 pairs it is possible to find best-fit values for the coefficients G and R_e using the entire data set.

In reality it is not so simple. At low signal levels the ADC converter may produce significant digitisation noise, and it is not R_e that is determined but B_e, the 'base level' noise. In practice there is also a non-Poisson noise component present which increases with the signal level, and it is necessary to add a quadratic or curvature term, cS^2, to the right-hand side of Eqn. 1. Additionally, the values of S and σ^2 range over several orders of magnitude, and it is usual—though arbitrary—to take the logarithm of Eqn. 1 in order that the largest values of S and σ^2 do not have a disproportionate effect on the determination of the coefficients. Modified, Eqn. 1 becomes

$$\log_{10}(\sigma^2) = \log_{10}(G^2 B_e^2 + GS + cS^2) \tag{2}$$

and it is this equation which is fitted to the experimental S–σ^2 values in order to obtain G, B_e and c.

Signals from a number of pixels cannot be analysed to obtain σ^2 because their variance is increased by the interpixel sensitivity differences illustrated in Fig. 1. Prabhu *et al.* (1992) suggest strategies that eliminate the effects of sensitivity variations through division or subtraction of flat-field images. Here, another approach has been adopted.

The determination of G, B_e and c has been made completely automatic and is programmed into the PM3000 computer. The LED flash ring is illuminated for varying intervals to produce varying signal levels without the need for any external light source to be set up. An area of 102×102 pixels is read out and stored. This procedure is repeated four times at each signal level. For reasons that are unclear, at higher signal levels the first image has a tendency to be slightly weaker than the subsequent ones (by $< 0.3\,\%$) and consquently is neglected. To remove the effect of any further inequality of illumination, the three remaining images are scaled to a common mean. (This correction

Table I: Gain and other properties of the Mt John Photometrics CCD system.

`cgain`	Gain G (ADU/e$^-$)	Inverse Gain $Q = G^{-1}$ (e$^-$/ADU)	Base level Noise, B_e (e$^-$)	Curvature c	Full-chip setup + readout time (s)
0	0.062 ±.002	16.2 ±.6	11.1 ±.6	1.1 ± .5 × 10^{-6}	4.9
33	0.114 ±.002	8.7 ±.2	8.0 ±.2	3.1 ± .5 × 10^{-6}	7.8
66	0.172 ±.002	5.8 ±.1	7.4 ±.1	5.5 ± .6 × 10^{-6}	11
100	0.232 ±.003	4.31 ±.06	7.1 ±.1	6.3 ± .7 × 10^{-6}	14
200	0.405 ±.006	2.47 ±.04	6.8 ±.2	7.2 ±1.3 × 10^{-6}	23
400	0.738 ±.015	1.36 ±.03	7.1 ± 2	1.4 ± .3 × 10^{-5}	40

is typically $< 0.3\,\%$.) Pixel-by-pixel means and variances between the three images are calculated for each of the 1024 central pixels and then are averaged to produce an $S - \sigma^2$ pair. Zero-illumination images are used to determine the 'fat zero' point on the ADU scale corresponding to $S = 0$. The default position of the 32×32 pixel region was selected to be in an area of the CCD of relatively uniform sensitivity. This default location is indicated by the black square in Fig. 1, but if desired the test region can be positioned elsewhere on the chip.

Twenty-five $S - \sigma^2$ pairs are obtained by varying the flash-ring illumination duration from 2 ms to sufficient to produce $S \simeq 15\,000$ ADU (the ADC saturates at 14 bits or 16 383 ADU). Least-squares best-fit values for the coefficients G, B_e and c are determined using the non-linear Marquardt algorithm (Press *et al.,* 1986). The mean scatter about the fit is used to determine the errors of the coefficients in the standard way.

Table I presents results for various values of `cgain`. The reported quantities derive from particular tests made during early 1992 and are arbitrarily selected: no attempt has been made to average several tests. Intercomparison of tests made on different occasions shows that the quoted errors are realistic. Fig. 2 presents data and fits (the so-called 'variance diagrams') for three values of `cgain`. There is a linear relation between G and `cgain`:

$$G = 0.00169 \cdot \texttt{cgain} + 0.062 \tag{3}$$

The digitisation noise introduced when $G^{-1} > R_e$ is evident in the values of B_e at low values of `cgain`. The readout noise R_e ($\simeq B_e$ for $G^{-1} < R_e$) is ∼7 electrons. The readout noise of the Mt John system is thus better than for the older Photometrics systems at Las Campanas and Kavelur, and the gain is higher.

With a fully-automatic gain-determination procedure it has been easy to check that G, B_e and c have no obvious variation with position on the chip, as expected. In *Use & Performance Note No. 5*

it was found that the system fat zero value depended on the temperature of the CE200 electronics box and the question was posed whether the gain might also be temperature dependent. Determinations made with the CE200 box at 8°C and 22°C showed no significant difference.

The noise for unexposed but normally-preflashed images is 18-19 electrons for all gains. This noise is relevant for dark sky backgrounds and between spectral orders.

Further comments should be made concerning the curvature term, cS^2. It represents extra noise at high signal levels. Since its effect is relatively small (increasing the noise, σ, at highest S by only 13-22 %, depending on gain) one cannot be sure that cS^2 is the physically correct parameterization of the effect. However, the residuals in Fig. 2 show that cS^2 is certainly adequate for practical purposes.

The physical cause of this extra noise is not clear. A number of prospective causes seem insufficient. It seems implausible that the photon statistics of the flash-ring LEDs could be the culprit. Experiments have been made on LED counting statistics using one of the Mt John single-channel photometers and the stabilised LED light source that has been constructed for test purposes (see Tobin & Wadsworth, 1991). The results are complex, but since for the gain and noise determinations larger signals are accumulated through longer integrations, any additional signal noise should be *reduced* at high levels. Further, some gain and noise determinations made using dome fluorescent lights as the light source resulted in very similar values for G, B_e and c, suggesting that the non-zero value of c is a real property of the CCD system and does not derive from the light source used. The ADC does sometimes suffer from binning bias in its last two bits (see §3 below), but numerical simulations have shown that many more bits would need to be affected to produced the observed excess noise. Further, the number of affected bits would have to be greater at greater gains. Since different gains result from properties of the amplifier train and not the ADC, a noise origin in the ADC seems unlikely. The most likely source for the extra noise is perhaps in the amplifiers. In any event, the practical effect of the curvature term is only small and occurs in a signal regième where the signal-to-noise ratios are high.

3. OTHER CHARACTERISTICS

A further quantity which may influence the observer's choise of `cgain` is the CCD setup and readout overhead (Table I), which increases dramatically as the integration times for correlated double sampling are increased at higher gain. For this reason, observers will probably wish to acquire targets with `0 cgain` even though observations are to be made at higher gain. The CCD has been reprogrammed to acquire an offset signal subsequent to each exposure in order to monitor the CE200 electronics box temperature drift discussed earlier. The setup and readout times reported in Table I include the time required to determine this offset.

Output signals are affected by a.c. pickup from the 50 Hz mains supply. This pickup is always present, but is most noticeable when it beats with the readout rate and results in diagonal bands across dark images. Because of their inclination, these bands can be difficult to subtract out in spectroscopy, and observers may wish to pseudo-randomise the pickup by slight adjustments either to `cgain` or to the area of the chip read out. The peak-to-peak amplitude of the pickup is ∼9 electrons at all values of `cgain` (i.e. r.m.s. $\sim 3\,e^-$). The effect of this pickup is of course included in the values of B_e and R_e.

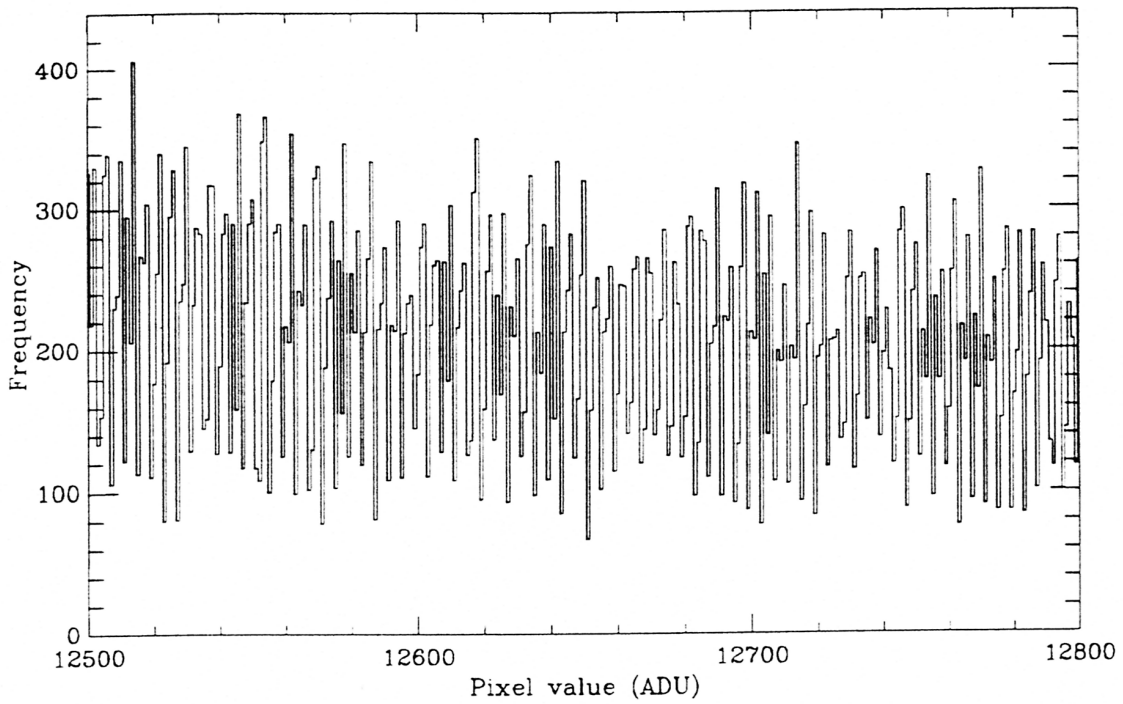

Figure 3: Part of the intensity histogram for a flat-field image acquired on 1989 July 3 at 0 `cgain`. The 'pattern of four' resulting from binning bias in the last 2 bits is very obvious.

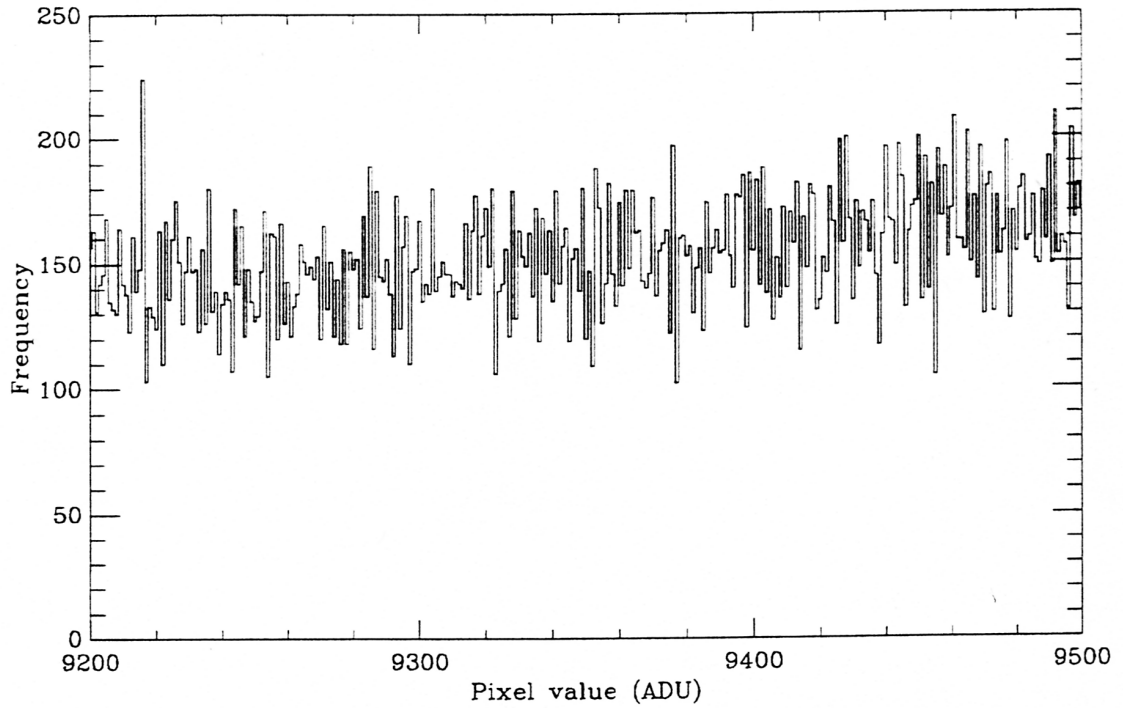

Figure 4: Part of the intensity histogram for a flat-field image acquired on 1992 February 25 at 66 `cgain`. There is no evidence of any strong binning bias.

Many-bit ADCs are sometimes subject to binning bias. At high signal levels, (i.e. when the highest-order bits are non-zero) the lowest-order bits may not set correctly but may exhibit a tendency to favour certain bit patterns and avoid others. Histograms of the intensity levels in well-exposed flat-field images easily reveal the presence of binning bias (e.g. Djorgovski, 1984). In the absence of binning bias, histograms of the frequency of intensities should show a smooth distribution. However when binning bias is present the histograms show a marked modulation with a power-of-two periodicity. Figs. 3 and 4 show that the Mt John ADC (a Burr Brown ADC76KG) is sometimes, but not always, subject to binning bias in the two lowest-order bits. (Fourier power spectra confirm that there is negligible effect in the 3rd lowest-order bit in Fig. 3 and that there no significant binning bias present in Fig. 4.) Observers should be aware that the specifications of the ADC76KG guarantee 'no missing codes' only for temperatures greater than 10°C. It is unclear whether the presence of binning bias in Fig. 3 and its absence in Fig. 4 is indicative of an erratic effect or is a consequence of different ADC temperatures in summer and winter. Observers should also be aware that a 5-minute warm-up time is specified for the ADC76KG. The claimed r.m.s. ADC noise is 0.08 ADU and the ADC can be and presumably has been fine trimmed to eliminate temperature sensitivity.

The CCD is sensitive to cosmic rays which produce spike-like spots of varying intensities, in extreme cases containing charges of several thousand electrons per pixel. The number that will be seen in any particular image depends on the noise level, but at low signal levels the full chip exhibits some 9 events per minute when in the McLellan Telescope dome at Mt John. Experience has shown that the radioactive glasses used in some camera lenses can produce an extremely large additional rate of cosmic-ray-like events.

ACKNOWLEDGEMENTS

I thank A.C. Gilmore for acquiring test LED photon counts and C.H. Rowe for suggesting the analysis of count differences as a way of eliminating supply fluctuations. I also thanks T.P. Prabhu, Y.D. Mayya and G.C. Anupama: refereeing their article for the *Journal for Astrophysics & Astronomy* revealed the necessity of the curvature term, cS^2, and provided the impetus for the preparation of the present paper.

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USE AND PERFORMANCE NOTES

No. 1: Tobin, W., 1990, *Description of the system.*

No. 2: Pollard, K., 1989, *Evaluation of the linearity of the Mt John CCD.*

No. 3: Pollard, K., 1989, *Evaluation of the spectral response for various operating temperatures of the Mt John CCD.*

No. 4: Hugtenburg, R., Tobin, W., 1990, *Flexure tests of the Mt John Boller & Chivens spectrograph as temporarily modified with a telephoto camera lens for use with the Photometrics CCD detector system.*

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No. 6: Tobin, W., 1991, *The Boller & Chivens intermediate resolution spectrograph.*

No. 7: Tobin, W., 1991, *Time keeping on the Photometrics CCD system.*

No. 8: Tobin, W., 1991, *Forth acquisition software.*

No. 9: Tobin, W., 1992, *Problems of CCD flat fielding.*

University of Canterbury Department of Physics & Astronomy

Mt John University Observatory

Mt John Photometrics CCD System

Use and Performance Note Number 11

SHUTTER MAP

W. Tobin

1993 April 23

These Notes are intended for guidance only: individual observers have the sole responsible for the integrity of their own data. Users of the CCD system are encouraged to summarize the performance that they obtain in a Note in this series. Contact Dr. W. Tobin to be allocated a series number.

SHUTTER MAP

W. Tobin

1993 April 23

1 Introduction

A mechanical shutter admits light to the detector chip of the Mt John Photometrics CCD camera system. The five petals of the shutter do not necessarily start to move immediately they are commanded so to do, nor is their motion instantaneous. With respect to this latter point, the *Photometrics 3000 User's Manual* claims that the shutter has '5 msec open and close times'. Finally, since the shutter on the CH210 camera head is located close to the CCD chip in a slow beam, different parts of the telescope beam are affected at different times when the shutter moves. In consequence actual exposure durations may differ from the requested exposure times, and differ according to location on the chip. This *Use & Performance Note* describes software that has been written to measure the shutter delay (the so-called 'shutter map') and presents some results. Actual exposures are from ~5–30 ms longer than requested exposure times and this may have practical consequences for flat fielding, for observations of photometric standard stars, and for speckle interferometry.

2 Theory

The method is essentially that described by P.B. Stetson, *Highlights of Astronomy* **8**, 635-644 (1989).

Suppose an exposure of duration τ actually takes $\tau + \delta(r, c)$ at pixel (r, c). The shutter map is $\delta(r, c)$ and in principle can be negative valued, for example if the shutter takes longer to open than to close. Let the chip be roughly uniformly illuminated with an unvarying flux of light. The observed ratio of two exposures of different durations τ_1 and τ_2 then provides a way of obtaining the shutter map because the expression for the ratio involves $\delta(r, c)$.

In practice, none of the smooth-field or flat-field calibration lamps available at Mt John is sufficiently stable to provide to provide an adequately unvariable flux ($\ll 0.2\%$). It is thus necessary to take a seqence of images with the two durations alternating ($\tau_2 : \tau_1 : \tau_2 \ldots : \tau_1 : \tau_2$). The means of the two subseries of different τ will cancel any first-order drifts in the illumination level. In addition, to minimise the effect of read-out noise, and to average over many shutter movements, it is desirable that each image read out is exposed to a roughly-similar ADU level. This is achieved by producing images that accumulate multiple exposures obtained by

opening and closing the shutter N times. The corresponding exposure duration at (r, c) is then $N(\tau + \delta(r, c))$. The resulting map is of course a *mean* shutter map.

Thus it is necessary to obtain two mean exposures which are averages of the following quantities:

$$N_1(\tau_1 + \delta(r, c))$$

and

$$N_2(\tau_2 + \delta(r, c))$$

where $\tau_2 > \tau_1$. (For example, the primary case implemented by the shutter-map software adopts $N_1 = 10$, $\tau_1 = 1\,\mathrm{s}$, $N_2 = 1$, $\tau_2 = 10\,\mathrm{s}$, which means that both images will contain approximately equal signals because $N_1\tau_1 = N_2\tau_2$.)

Calculate the ratio:

$$R(r, c) = \frac{N_1(\tau_1 + \delta(r, c))}{N_2(\tau_2 + \delta(r, c))}$$

Therefore

$$N_2\tau_2 R(r, c) + N_2\delta(r, c)R(r, c) = N_1\tau_1 + N_1\delta(r, c)$$

or

$$N_2\tau_2 R(r, c) - N_1\tau_1 = \delta(r, c)(N_1 - N_2 R(r, c))$$

or

$$\delta(r, c) = \frac{N_2\tau_2 R(r, c) - N_1\tau_1}{N_1 - N_2 R(r, c)}.$$

This last equation is the basis of the calculation of the shutter map.

The PM3000 uses 16-bit integer arithmetic for images. For this numeric reason it is necessary to calculate scaled quantities:

$$R'(r, c) = 10\,000 \cdot R(r, c)$$

and

$$\delta'(r, c) = 10\,000 \cdot \delta(r, c).$$

Therefore

$$\delta'(r, c) = 10\,000 \times \frac{N_2\tau_2 R'(r, c) - 10\,000 N_1\tau_1}{10\,000 N_1 - N_2 R'(r, c)}$$

or, since no intermediate number in this calculation must exceed $\pm 32\,767$ (except the scaled ratio, which can be produced with the Photometrics FORTH command `i*/`):

$$\delta'(r, c) = 10\,000 \times \frac{(N_2/N_1)\tau_2 R'(r, c) - 10\,000\tau_1}{10\,000 - (N_2/N_1)R'(r, c)}.$$

It is this equation that is used for the calculation of the shutter-map frame. Since τ is given in seconds, the units of $\delta'(r, c)$ are $10^{-4}\,\mathrm{s}$.

3 Implementation

The shutter-map software is in a special file called `shutter`. It must be loaded using `1f shutter` *after* `mtjohn` has been loaded. When no longer required, the `shutter` words can be discarded from the FORTH dictionary using `forget -shutter`

The individual shutter-map words are not concatenated into one final, single FORTH word [c.f. `determine_gain` (*Use & Performance Note No. 9*)]. This is because it can be desirable to examine intermediate frames before proceeding to the calculation of the shutter map.

The sequence of operations to follow is:

1. Type `setccd` This word clears the image caches because the software puts intermediate frames in fixed cache positions. Twenty-nine image caches are required. It is thus not possible to use full frames of 384 × 576 pixels so `setccd` sets 2 × 2 binning.

   The images caches are used as follows:

Cache	Use
1	Inaccessible [Work Area]
2	DARK
3	1st exposure $N_2(\tau_2 + \delta(r,c))$
4	1st exposure $N_1(\tau_1 + \delta(r,c))$
5	2nd exposure $N_2(\tau_2 + \delta(r,c))$
6	2nd exposure $N_1(\tau_1 + \delta(r,c))$
7	3rd exposure $N_2(\tau_2 + \delta(r,c))$
8	3rd exposure $N_1(\tau_1 + \delta(r,c))$
9	4th exposure $N_2(\tau_2 + \delta(r,c))$
10	4th exposure $N_1(\tau_1 + \delta(r,c))$
11	5th exposure $N_2(\tau_2 + \delta(r,c))$
12	5th exposure $N_1(\tau_1 + \delta(r,c))$
13	6th exposure $N_2(\tau_2 + \delta(r,c))$
14	6th exposure $N_1(\tau_1 + \delta(r,c))$
15	7th exposure $N_2(\tau_2 + \delta(r,c))$
16	7th exposure $N_1(\tau_1 + \delta(r,c))$
17	8th exposure $N_2(\tau_2 + \delta(r,c))$
18	8th exposure $N_1(\tau_1 + \delta(r,c))$
19	9th exposure $N_2(\tau_2 + \delta(r,c))$
20	9th exposure $N_1(\tau_1 + \delta(r,c))$
21	10th exposure $N_2(\tau_2 + \delta(r,c))$
22	10th exposure $N_1(\tau_1 + \delta(r,c))$
23	11th exposure $N_2(\tau_2 + \delta(r,c))$
24	Mean of 11 τ_2 exposures
25	Mean of 10 τ_1 exposures
26	$R'(r,c)$
27	$(N_2/N_1)\tau_2 R'(r,c) - 10\,000\tau_1$
28	$10\,000 - (N_2/N_1)R'(r,c)$
29	$\delta'(r,c)$

2. Set `cgain` to the desired value. Shortest read-out times and presumably best signal-to-noise ratios are obtained with `0 cgain`

3. Acquire and store a dark frame in cache 2. `Setccd` does not actually allocate the 29 caches. If `median` is to be used to obtain a median dark frame, cache 2 must first be filled, then the three individual darks must be acquired into caches 3, 4 and 5. Finally, `median` can be used to put the median dark in cache 2.

4. Set up illumination of the chip such that a dark-subtracted τ_2=10 s exposure results in ∼10,000 ADU at the chosen value of `cgain`. Photometry flat-field lamps or the échelle spectrograph smooth field lamp with a sufficiently-long slit length and appropriate slit width can be employed. If the signal level is grossly different from 10 000 ADU there is

the risk of integer over- or under-flow in the calculation of the shutter map. (Over- or under-flow should be immediately apparent because adjacent pixels in the shutter map will vary from $\sim +32\,767$ to $\sim -32\,767$.

5. Use `shmapseq` to obtain a sequence of 11 $N_2 = 1$, $\tau_2 = 10\,\mathrm{s}$ exposures and 10 $N_1 = 10$, $\tau_1 = 1\,\mathrm{s}$ exposures in caches 4-23.

   NOTE The exposures are timed by the seconds ticking of the SmartWatch clocks card (as with `expose` and `readout`) and are accurately integral numbers of seconds (to 1 part in 10^5). As discussed in *Use & Peformance Note No. 7*, the clock used to time `obs` exposures runs ~4.3% fast.

6. (OPTIONAL) At this juncture it is probably advisable to examine the sequences of images to check that the signal levels are closely constant. The word `exsmodd` first calculates the mean of the 11 frames in caches 3, 5...23 (this takes several seconds) and then performs a `134 154 prows` on the mean (`134 154 prows` plots a 20-superpixel wide band down the middle of the 2×2 binned image). `Exsmodd` next performs `oplot 134 154 prows` on each of the 11 individual images in turn. The plots can be directed as desired to video overlay plane or HDS Tektronix-mode screen with `splot` and `tplot`. Paper copies of the HDS plots can be made with `tekprint`. If any of the individual images deviates significantly from the mean, either the whole sequence can be reacquired, or it can be replaced by an adjacent image of appropriate τ by `n cachecopy`. The word `exsmeven` performs the same functions on caches 4, 6...22.

7. Use `calc_delta` to calculate the shutter map in cache 29 in units of $10^{-4}\,\mathrm{s}$. This word also calculates the contents of the intermediate caches 24-28, which can be examined, if desired with `show`, `sho` or `qshow`.

8. The shutter map can now be saved to tape, e.g. for the plotting of contour maps with MIDAS, and for use in correcting calibration images (see below). Other frames can also be stored should the user e.g. wish to calculate the shutter map using real arithmetic on a more advanced image-analysis system, or want to investigate the variability of individual shutter openings and closings from a comparison of the individual $N(\tau + \delta(\tau, c))$ frames (but this must be disentangled from variations in the illumination level). (Investigation of the variability of shutter opening and closing times is however probably best investigated by taking exposures of single opening and closings.)

A further shutter-map option is available for speckle interferometry tests. Individual shutter-openings are synchronised with the SmartWatch seconds ticks, but the closing command follows a number of milliseconds later. The number of milliseconds is stored in the 4-byte integer variable `shortime` which can be examined with `shortime ?` and altered with e.g. `5 shortime !` In step (5) above the word `shmapseq` must be replaced by `spklshmapseq` which obtains exposure sequences with $N_1 = 100$, $\tau_1 =$`shortime` ms and $N_2 = 10$, $\tau_2 = 1\,\mathrm{s}$. To calculate the shutter map in step (7), `calc_delta` must be replaced with `calc_spkl_delta`

4 Results

Figures 1 and 2 present a sample shutter map acquired with $N_1 = 10$, $\tau_1 = 1\,\mathrm{s}$ and $N_2 = 1$, $\tau_2 = 10\,\mathrm{s}$. Figure 1 is a grey-scale representation; Figure 2 is a smoothed contour map produced by MIDAS with the contours marked in millisecond (*not* 10^{-4}s). The smooth-field lamp of the

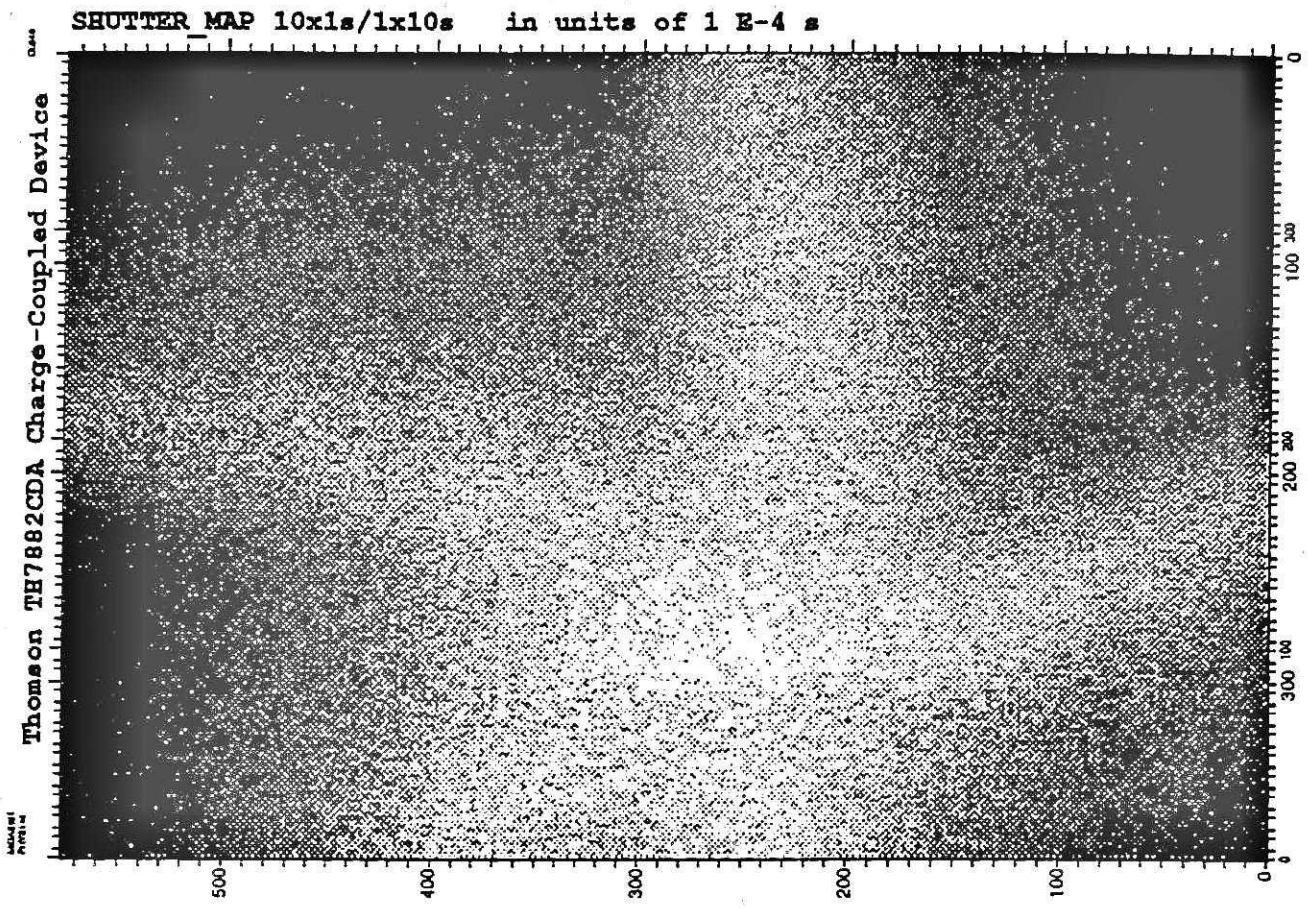


Figure 1: Shutter map: grey scale representation (lighter=longer opening). The read-out point is at upper right.

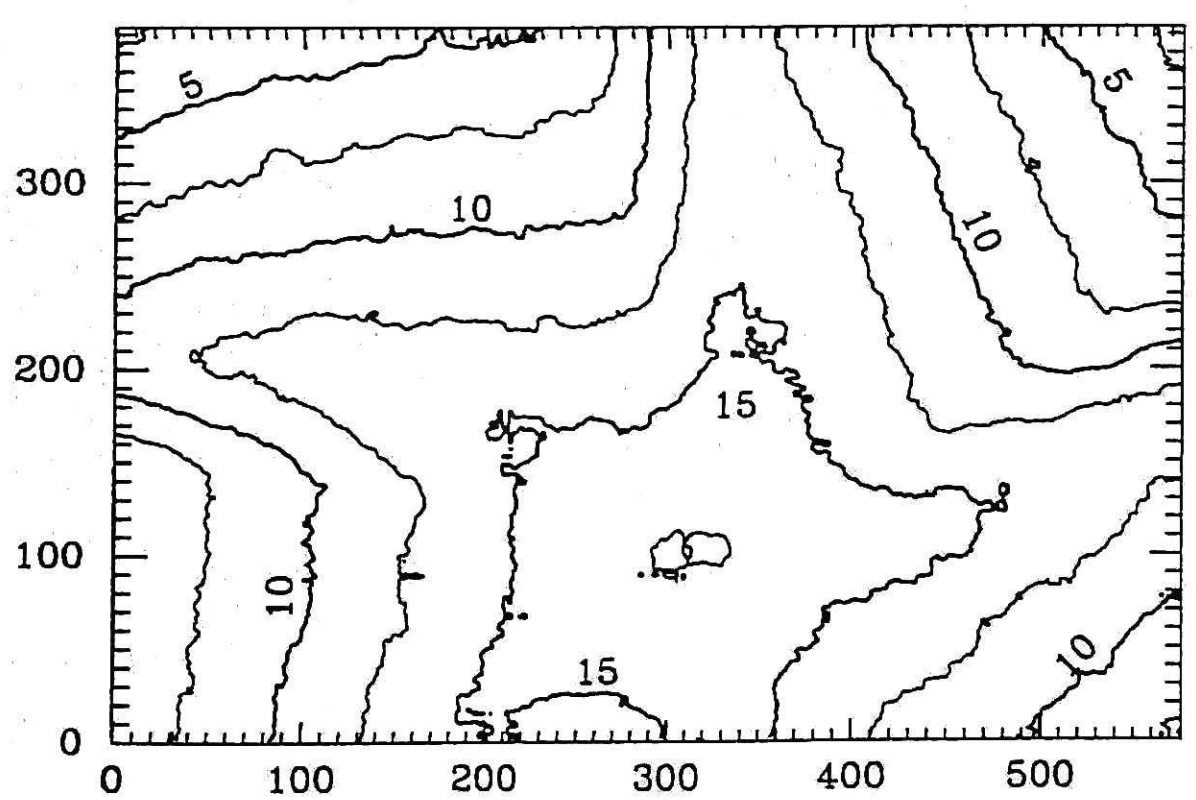


Figure 2: Shutter map: contour presentation, smoothed over 4×4 (super)pixels, contours marked in millisecond. The read-out point is at upper right.

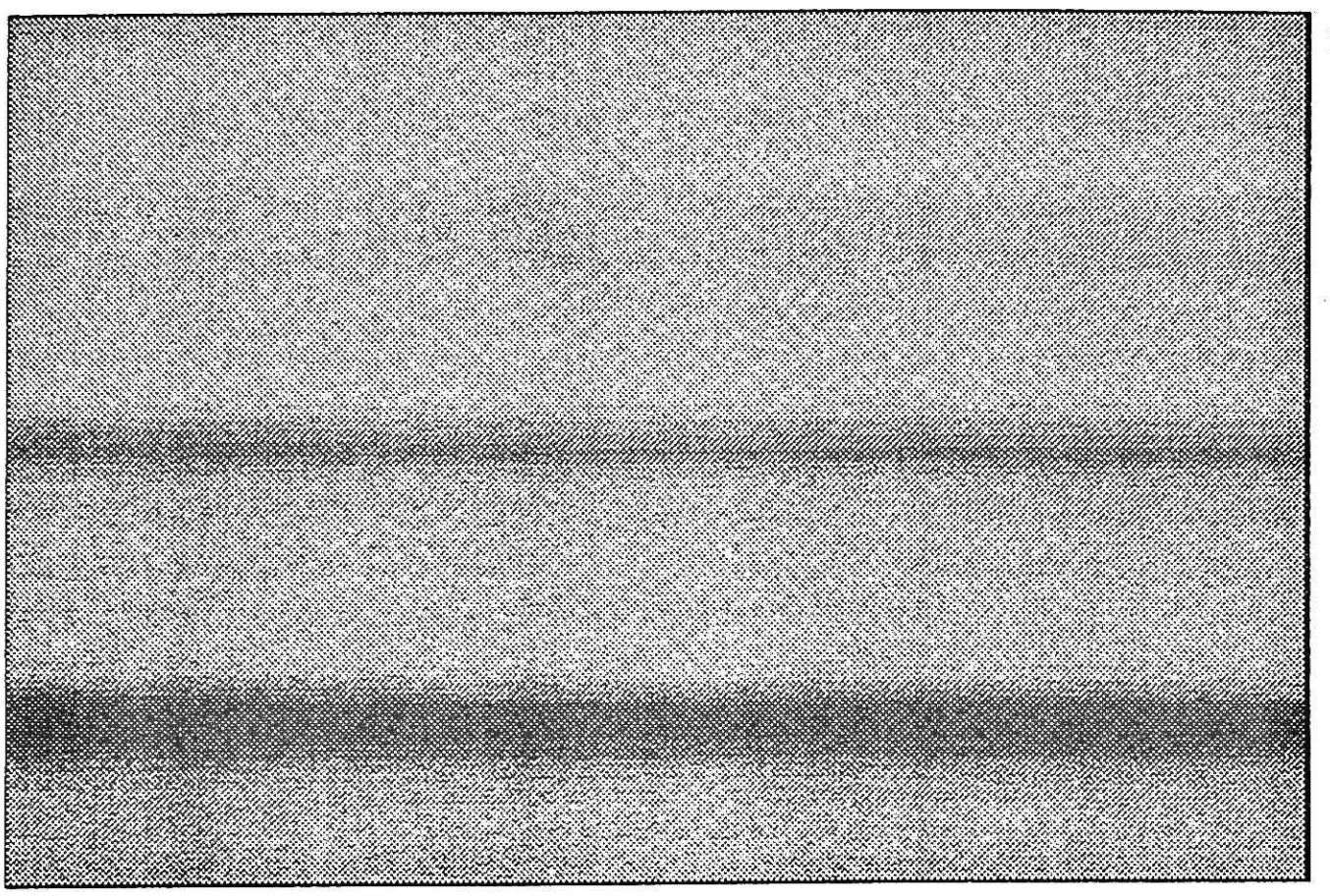


Figure 3: The chip illumination used for the shutter map determination. The échelle spectrograph smooth-field lamp was was used with the infra-red cross grating and cross-grating micrometer setting = 1.471, slit width micrometer setting = 460 and échelle tilt micrometer setting = 454.

échelle spectrograph was used for the illumination: Figure 3 represents the illumination in grey scale; Figure 4 is a plot across the central 20 columns of superpixels (obtained with the MIDAS commands `average/row aver =` *shutter_map_name* `134,154` and `plot/row aver`).

The shutter map is seen to exhibit the five-petalled structure of the shutter. There is no indication of contamination by the stripy form of the illumination. The offset of the Thomson chip from the centre of the dewar (and shutter) is readily apparent. The value of $\delta(r, c)$ varies from $\sim$ 5 ms to $\sim$ 18 ms, somewhat greater than expected from the supplier's claim of 5 ms opening and closing times. Tests suggest the shutter map is somewhat variable (at the few millisecond level).

Shutter maps obtained with `spklshmapseq` and `calc_spkl_delta` show longer delays of up to almost 30 ms. It is understood that the shutter is opened by an initially large current which subsequently is reduced to a lower level sufficient to maintain the shutter open but motionless. With short `spklmapseq` exposures perhaps either the still-present initial large current or induction effects delay the closing of the shutter. However the shutter speed near the periphery of the CCD chip appears to be sufficiently fast to be useful in speckle work.

Users for whom the shutter speed is crucial should investigate it further.

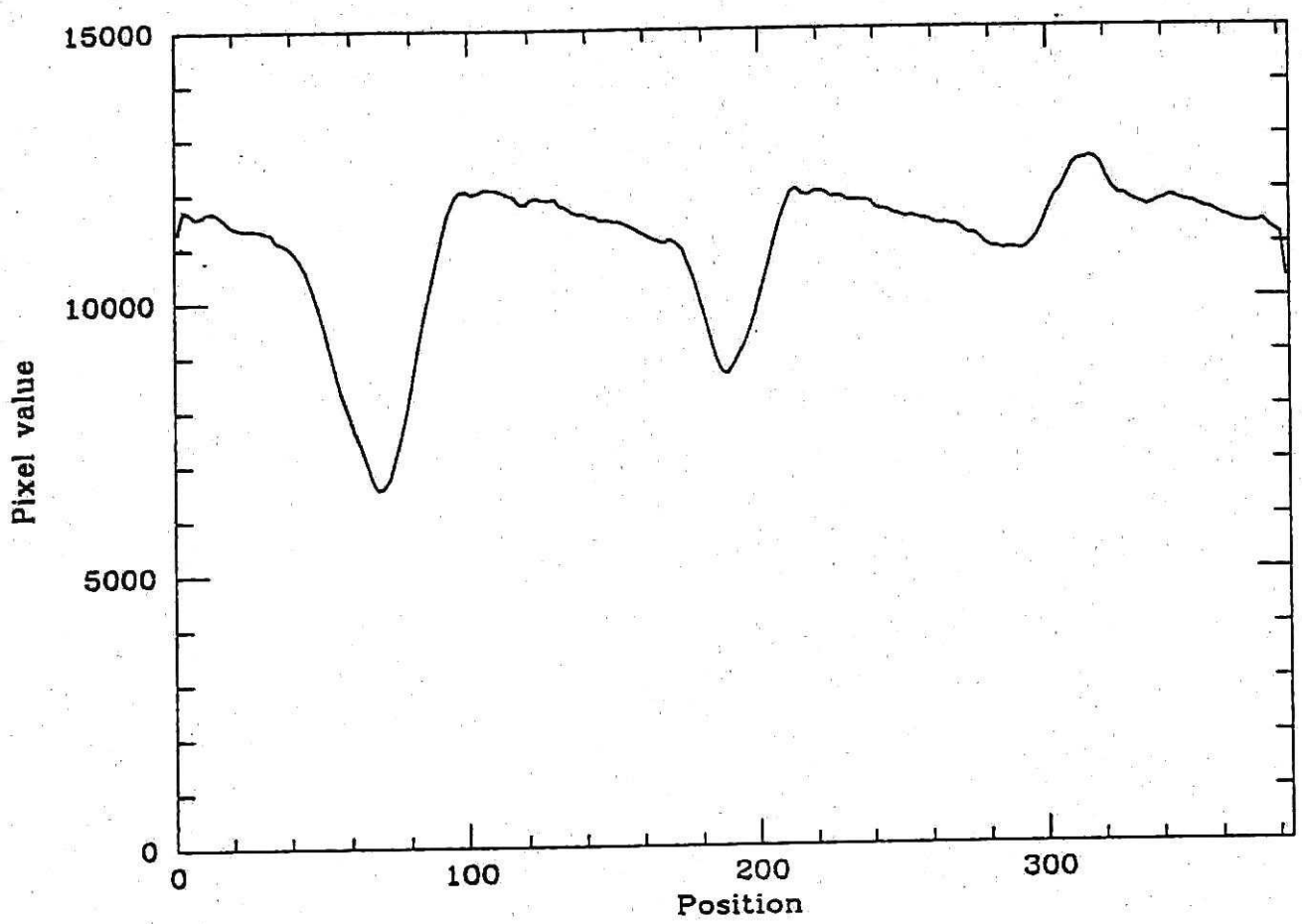


Figure 4: A vertical cut through the centre of Fig. 3 (average of 20 superpixels).

5 Corrections for shutter speed

If it is desired to calculate a science or calibration image $I'(r', c')$ which is corrected for the effect of shutter speed from an image $I(r', c')$ of nominal duration τ, the following equation must be used in a high-level image-analysis system:

$$I'(r', c') = I(r', c') \times \frac{\tau}{\tau + \delta(r, c)}$$

where care must be taken to ensure that an appropriate expression is used to relate the pixels (r', c') of the science or calibration image with the superpixels (r, c) of the 2×2-binned shutter map. The nominal value of τ may need correcting in the case of very short exposures acquired with commands such as `obs` which time using the incorrect rate of the CE200 clock.

The VAX/VMS tape-reading commands `$ccd_to_vax` and `$fast_ccd_to_vax` write shutter map and other frames to disk with the following keyword values:

Keyword	Meaning	Value for 2×2-binned shutter map	Value for arbitrary image
NAXIS1	No. columns	192	NCOLS
COL-OSET	Column offset in pixels	0	ICOLORG
COL-BNNG	Column binning	2	ICOLBIN
CRPIX1	MIDAS reference pixel	1	1
CRVAL1	Coordinate at reference pixel	1.5	ICOLORG+(ICOLBIN+1)/2
CDELT1	Coordinate increment per pixel	2	ICOLBIN
NAXIS2	No. rows	288	NROWS
ROW-OSET	Row offset in pixels	0	IROWORG
ROW-BNNG	Row binning	2	IROWBIN
CRPIX2	MIDAS reference pixel	1	1
CRVAL2	Coordinate at reference pixel	1.5	IROWORG+(IROWBIN+1)/2
CDELT2	Coordinate increment per pixel	2	IROWBIN

(Note [1] that 'columns' and 'rows' above refer to the columns and rows of the chip itself (columns run parallel to the channel stops); [2] that while the Photometrics system begins numering pixels from (0,0) adjacent to the read-out point, FITS and MIDAS start numbering from (1,1) with the column-number axis running in the opposite sense to the Photometrics one; and [3] that COL-OSET, COL-BNNG, ROW-OSET and ROW-BNNG are given in physical chip pixels.)

Users may find these keyword values (which contain redundancy) useful for calculating pixel correspondences $(r', c') \longleftrightarrow (r, c)$.

In MIDAS (91 NOV version) the shutter map may be expanded up to a full 384×576 image using the following command:

REBIN/LINEAR *shutter_map* out 1.,1. -1.,-1. 1.,1.

where out.bdf will hold the expanded shutter map. It should be noted that the various MIDAS commands for smoothing alter the signal levels. A user who smooths a shutter map must be careful to rescale it appropriately afterwards. In practice, it may be preferred to average several independent shutter maps in order to produce a smoothed shutter map.

6 Conclusions

In normal circumstances the mechanical shutter takes between ~ 5 and ~ 20 ms to open and close. The delay can increase to ~ 30 ms for the very short exposures needed for speckle interferometry.

The finite 5–20 ms shutter delay will not introduce any significant systematic errors in photometry science images with exposures longer than ~ 10 s. However it may well be necessary to correct exposures of standard or other bright stars.

Flat-field images may also be affected. For example, the shutter delay produces up to $\sim 2\%$ error in a dome flat-field obtained with `10 obs`. It is probably preferable to lengthen exposure times by the use of attenuating filters in front of the board-illuminating lamps rather than to try to correct the dome flats in the way described in the previous section. (This is because the correction is a mean correction: if the shutter actually moves erratically, the appropriate correction for a short image may be significantly different.)

For speckle work, the maximum shutter delay can be avoided by observing with areas of the chip where the delay is less.

University of Canterbury Department of Physics & Astronomy

Mt John University Observatory

Mt John Photometrics CCD System

Use and Performance Note
Number 12

McLELLAN TELECOPE
f/8 SEEING VALUES
IN THE GREEN

J.D. Pritchard

1993 June 23

These Notes are intended for guidance only: individual observers have the sole responsible for the integrity of their own data. Users of the CCD system are encouraged to summarize the performance that they obtain in a Note in this series. Contact Dr. W. Tobin to be allocated a series number.

McLellan Telescope
f/8 Seeing Values in the Green

J.D.Pritchard.

1993 June 23

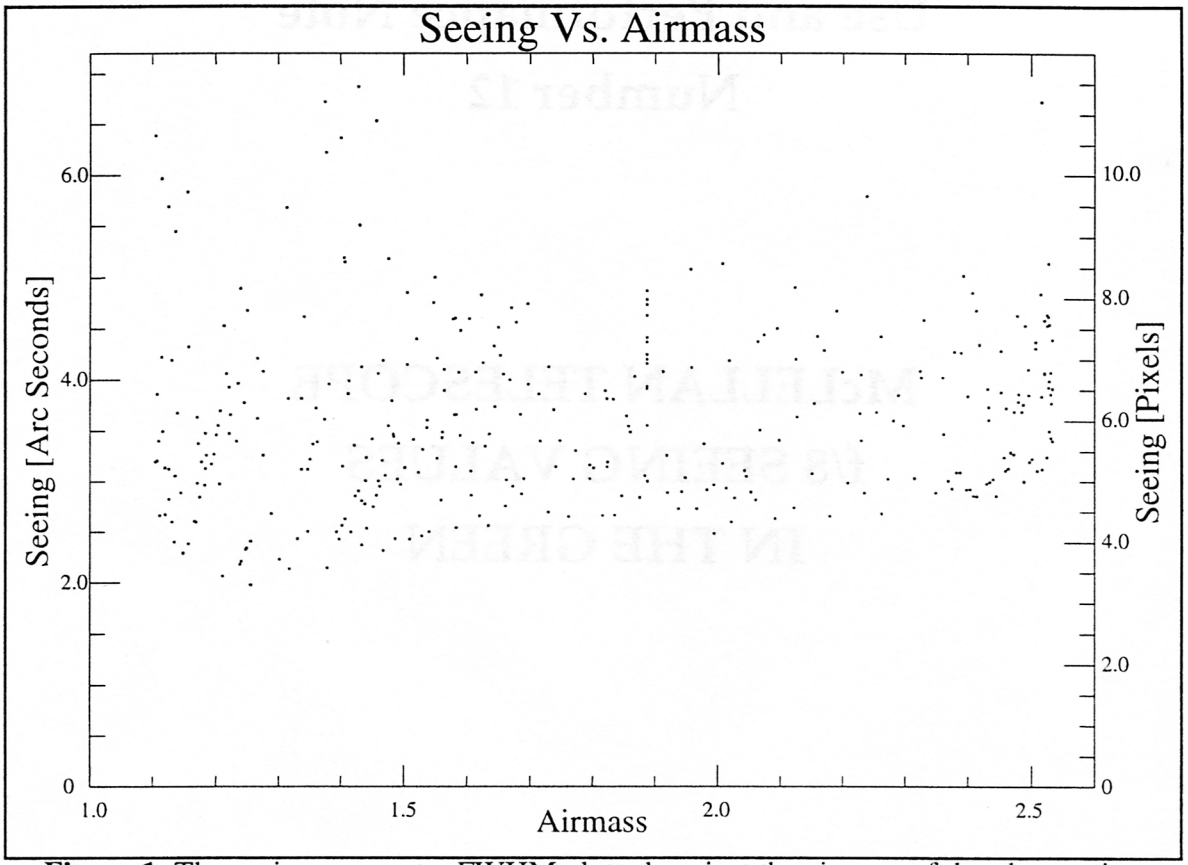


Figure 1: The seeing parameter FWHM plotted against the airmass of the observation

Seeing is a critical quantity for both photometry and spectroscopy. It thus seems useful to disseminate quantitative values obtained over the last seven months using the McLellan 1m Telescope at *f*/8 focus.

Figure 1 shows the Full Width at Half Maximum Seeings obtained from CCD imaging photometry between November 1992 and May 1993. These values derive from 354 observations on 19 nights of a field in the Large Magellanic Cloud using the new Photometer Head and a *Johnson V* filter (~550 nm). Most of the exposures were 400 s long and the FWHM values were derived from Point Spread Functions fitted by the two-dimensional photometry package DAOPHOT.

Figure 1 shows that the dependence of seeing on airmass is only weak. The best seeing obtained was 2.0 arcsec (3.2 pixels), with a mean of 3.6 arcsec (6.0 pixels) and an r.m.s. scatter of 0.9 arcsec (1.4 pixels). The best seeing is not as good as that obtained with the Boller & Chivens in 1990 (eg Watson *etal*, MNRAS **258**, 527 or Tobin *etal*, MNRAS **260**,777) but the average is better. It is difficult to ascribe a clear reason for these differences. These values are of course biased since data was not collected on nights of particularly bad seeing. Users should also note that bad seeing can take two general forms: nights when the stellar images are broad yet positionally stable, and nights when the images are sharper but wander significantly. These differences are not discernible in 400 s exposures.

University of Canterbury Department of Physics & Astronomy

Mt John University Observatory

Mt John Photometrics CCD System

Use and Performance Note
Number 13

CHRISTCHURCH
VMS-BASED
SOFTWARE

W. Tobin

1993 August 2

These Notes are intended for guidance only: individual observers have the sole responsible for the integrity of their own data. Users of the CCD system are encouraged to summarize the performance that they obtain in a Note in this series. Contact Dr. W. Tobin to be allocated a series number.

CHRISTCHURCH VMS-BASED SOFTWARE

W. Tobin

1993 August 2

1 Introduction

A suite of Fortran programs and VMS command files for handling MJUO CCD data has been produced which runs on the University of Canterbury VAX/VMS cluster in Christchurch. The suite is essentially complete, though the individual programs will undoubtedly still be subject to minor modifications. The programs' functions include:

1. Updating files of target coordinates and CCD clock drift (essential for calculation of targets' airmass, heliocentric observation time, etc.)
2. Reading 9-track data-transfer and archive tapes, which are written by the Photometrics CCD system at MJUO in an idiosyncratic format, and converting the data into FITS format on disk.
3. Creating printable and viewable log files summarizing header information from the images on data-transfer and archive tapes.
4. Creating log files of the science images of particular targets.
5. Creating PostScript files for printing paper copies of images.
6. Creating PostScript files for producing sky-survey overlays to aid setting the azimuth and radius values for the offset-guider camera in the CCD photometer head.
7. Displaying on-line lists of Mt John CCD publications.
8. Miscellaneous functions.

To have access to these functions a user needs to have an account within the `[PHYS]` group on the University VAX cluster and to include the following statement in the `login.com` file:

```
@uoc$user1:[phys147.ccd]photometrics_ccd.com
```

Users at other sites or on other clusters will need a different statement, and some of the details in this *Use & Performance Note* may be inappropriate.

NOTE: CANTVA, currently a 32-bit VAX7600, is due for change to a 64-bit Alpha system in 1993/4. The 32-bit VMS machines in the cluster (notably PHYSSA) will then require different

executable images from the 64-bit CANTVA. The programs have been structured so that the correct executables should be invoked automatically.

The programs require the following peripherals: (i) VT220-style terminals or emulators (80- and 132-column modes); (ii) PostScript printers; and (iii) 9-track, 1600-bpi-capable tape drives.

All commands are designed to be used interactively, though `hardcopy` can be run in batch. The list of available commands can be obtained by typing (user input in **bold**):

$helpccd

whereupon a brief description similar to the following will appear on the user's terminal:

```
.-----------------------.-------------------------------------------------------.
| Command               | Function                                              |
|-----------------------|-------------------------------------------------------|
| $ccdo*verlay          | CCD photometer offset guider setting overlay          |
| $ccdp*ublications     | Type list of MJUO CCD publications                    |
| $ccd_to_vax           | Copy data transfer tape to disk FITS format           |
| $copyccdcd            | Copy clock drift file to user's disk                  |
| $copyccdp*ublications | Copy list of MJUO CCD publications to user's disk     |
| $copyccdt*argets      | Copy CCD target list to user's file                   |
| $copyh*elpccd         | Copy this help file to user's disk                    |
| $copyp*rocessstape    | Copy .com file for batch $hardcopy to user's disk     |
| $copyupn              | Copy 'Use & Performance Notes' list to user's disk    |
| $edccdcd              | $edit CCD clock drift file                            |
| $edccdt*argets        | $edit CCD target coordinates file                     |
| $edpccdcd             | $edp  CCD clock drift file                            |
| $edpccdt*argets       | $edp  CCD target coordinates file                     |
| $edrccdcd             | $edr (read only) CCD clock drift file                 |
| $edrccdt*argets       | $edr (read only) CCD target coordinates file          |
| $edtccdcd             | $edt  CCD clock drift file                            |
| $edtccdt*argets       | $edt  CCD target coordinates file                     |
| $fast_ccd_to_vax      | As $ccd_to_vax but no clock-drift & coords preview    |
| $fits*edit            | Edit FITS header                                      |
| $hardcopy             | PostScript image file from an *.MT FITS file          |
| $helpccd              | Type this help                                        |
| $old_ccd_to_vax       | Previous vers'n of $ccd_to_vax (usually unavailable)  |
| $sorto*bslog file.ext | Temporal sort of an observing-log file                |
| $unixtime             | Convert TICKS to UT date and time                     |
| $updateccd            | Purge clock-drift and target coordinates files        |
| $upn                  | Type list of 'Use & Performance Notes'                |
|-----------------------------------------------------------------------------|
| * indicates point at which a command may be abbreviated                     |
'-----------------------------------------------------------------------------'
```

2 Tape-reading and associated commands

The tape-reading program (`ccd_to_vax`) requires input from four sources: (i) the command terminal; (ii) the 9-track tape; (iii) a file of target names, coordinates and other details; and (iv) a file that tabulates the drift of the CCD clock from UTC. If the target-name and clock-drift files are not up to date, airmasses, heliocentric Julian dates, etc. may not be calculated or may be incorrect.

2.1 Target-name file

The target-name file contains the ASCII strings employed by the observers on the PM3000 system to identify their targets, the coordinates of each target (at any convenient epoch) and, if desired, the name of a file into which a log of observations (see below) will be written for each target. It also contains the names used to identify various calibration images and flags `c`, `*` and `e` to identify calibration ojects, targets and the end of the file, respectively.

The commands

$edpccdt*argets
$edtccdt*argets
$edrccdt*argets
$edccdt*argets

set the user's terminal to 132-column mode and invoke the `edp`, `edt`, `edr` and `edit` editors respectively. [The *s indicate the point at which each command may be abbreviated.] The interest of the `edr` (read-only) editor is that it can be used on the noisy PACNET line from Mt John without fear of accidental corruption of the file. The editors are exited via **Ctrl-Z**.

Extracts from the target file are shown overleaf. Lines beginning with an exclamation mark are treated as comments and are included for human readability. When the tape-reading software `ccd_to_vax` is attempting to decode an image header it takes the name from the first name field of the target file (i.e. `DOME_FLAT`) and then scans the image-header comment field from left to right until it finds a match (delimited by blanks, and without regard to case). The image target is then identified. If no identification is found, the second name from the target file is taken (`SKY_FLAT`), and then if necessary the third name, and so on, until either an identification is found or the target is declared unrecognised.

Users should note that this procedure means that:

1. Compound target names must be concatenated to a single ASCII string with a character such as '_'

2. Names such a `U_Mon` and `u_mon` are considered identical

3. `Th_arc for U_Mon` is identified as '`Th_arc`', not '`U_Mon`'.

4. `A poorly-focused image of Arcturus` is identified as '`Arcturus`'.

5. If a particular name appears more than once in the file, the coordinates and `.obslog` file name (if any) will be taken from the first occurence.

For unknown reasons, the PM3000 FORTH system occasionally loses the first character in the image-header comment field. To compensate, the target-name identification search is also performed omitting the first character of each name in the target-name file. It should thus be unnecessary to list targets twice, as, for example, `HV_2208` and `V_2208`. However, if names are entered incorrectly on the PM3000 system there is no practical way to correct these errors once an image has been written to 9-track tape, and a user will probably be obliged to include these incorrect names in the Christchurch target-name file.

The target-name file is read by `ccd_to_vax` via a formatted read, so it is important that all items occur in the correct columns. The required format should be self-evident from the example below.

If it is desired to accumulate a summary of the images associated with any particular target (in an `.obslog` 'observing log' file) the file's *full* description should be entered in the appropriate spaces (see also Section 4 below). A single observing log file name can of course be specified for stars known by several different names.

It is up to users to determine their own naming conventions for their targets (e.g. whether catalogue names and numbers should or should not be separated by underscores). Service observers at Mt John must obviously be advised of these names!
Sample target-name file:

```
! Lines begining with ! are comment lines and can extend right across the line.....................................
!
! Do not use <TAB> in filling in this table--spaces only
!
! Calibrations must precede celestial targets to ensure that images such as 'HeAr for LS_99' are recognised as calibrations
!                Must put     c    in this  columnn to identify calibration names
DOME_FLAT                     c
SKY_FLAT                      c
MOON_FLAT                     c
SMOOTH_FIELD                  c
HeAr                          c
Arc                           c
Th_arc                        c
! William Tobin objects
!---------Target name--------  * EPOCH- HH MM SS.S DDD MM SS.S ----Full identification of observing-log file, if wanted----
LSS_4300                      * 1950.0 17 34 37.5 -35 21 21.0
E218                          * 1980.0 04 03 12.  -44 43 00.
cpd-61d455                    * 1950.0 05 22 59.8 -60 58 12   uoc$user1:[phys146.observing_logs]cpdm61d455.obslog
cpd-61_455                    * 1950.0 05 22 59.8 -60 58 12.  uoc$user1:[phys146.observing_logs]cpdm61d455.obslog
HR1423                        * 2000.0 04 29 06.9 -13 02 55.
theta_Oct                     * 2000.0 00 01 35.8 -77 03 57.
BL_Tel                        * 2000.0 19 06 38.2 -51 25 03.1
HR_4064                       * 2000.0 10 21 01.9 +02 17 23.
CD-23_12460                   * 1950.0 15 37 42.  -24 05 44.
BD+2_2711                     * 1950.0 13 39 46.1 +01 45 25.0
BD+2d2711                     * 1950.0 13 39 46.1 +01 45 25.0
HD_119608                     * 1950.0 13 41 48.2 -17 41 10.9
HD_120086                     * 1950.0 13 44 44.  -02 12 00.
Arcturus                      * 2000.0 14 15 39.6 +19 10 57.
WT026bis                      * 1992.  21 11 50.6 -15 28 44.  uoc$user1:[phys146.observing_logs]wt026bis.obslog
BI141                         * 1991.  05 19 07.  -69 39 06.  uoc$user1:[phys146.observing_logs]bi141.obslog
! Steve West objects
!---------Target name--------  * EPOCH- HH MM SS.S DDD MM SS.S ----Full identification of observing-log file, if wanted----
HV_2208                       * 1990.0 01 16 45.0 -72 30 00.0
HV2208                        * 1990.0 01 16 45.0 -72 30 00.0
HV-2208                       * 1990.0 01 16 45.0 -72 30 00.0
V_2208                        * 1990.0 01 16 45.0 -72 30 00.0
!
! John Pritchard objects
!---------Target name--------  * EPOCH- HH MM SS.S DDD MM SS.S ----Full identification of observing-log file, if wanted----
A_FOCUS_STAR                  c
! LMC
HV_00936                      * 1992.6 05 20 35.0 -69 42 43.0 UOC$USER1:[PHYS249.MAGCLOUD.LMC.HV_00936]HV_00936.OBSLOG
HV_00982                      * 2000.0 05 29 52.3 -69 09 22.9 UOC$USER1:[PHYS249.MAGCLOUD.LMC.HV_00982]HV_00982.OBSLOG
! SMC
HV_01620                      * 2000.0 00 54 38.6 -72 32 04.8 UOC$USER1:[PHYS249.MAGCLOUD.SMC.HV_01620]HV_01620.OBSLOG
!  Bob Watson object
!---------Target name--------  * -EPOCH HH MM SS.S DDD MM SS.S ----Full identification of observing-log file, if wanted----
GX1+4                         * 1950.0 17 28 57.8 -24 42 45.  uoc$user1:[phys146.observing_logs]gx1plus4.obslog
GX2+5                         * 1950.0 17 28 57.8 -24 42 45.  uoc$user1:[phys146.observing_logs]gx1plus4.obslog
3U1728-24                     * 1950.0 17 28 57.8 -24 42 45.  uoc$user1:[phys146.observing_logs]gx1plus4.obslog
!  The next but one line line, which does not have to appear, indicates the end of the file.
!  Note the absence of any initial '!', the position of 'e' in column 30, and the blank spaces from column 30 onwards.
End of file                   e
[EOF]
```

Note concerning epochs and equinoxes: For the highest accuracy, both the epoch and equinox of coordinates should be quoted, and proper motions are needed to obtain coordinates at other epochs. Here, as is usual for lower-precision work, it is implicity assumed that proper motions are negligible so that the equinox and epoch of the quoted coordinates are the same.

2.2 The clock-drift file

Users are responsible for monitoring the drift of the PM3000 clock card to the accuracy necessary for their scientific programme, and for entering values of the offset (UTC-clock card) in the Christchurch clock-drift file. The commands for editing the clock-drift file are:

$edpccdcd

$edtccdcd
$edrccdcd
$edccdcd

The tape-reading software needs to know the clock drift as a function of the clock card 'ticks': the appropriate value of `TICKS` is displayed by the various FORTH clock words available through the PM3000 `mtjohn` extensions (e.g. `clockread`). The other fields in the clock-drift file are purely to increase clarity for humans.

The format of the clock-drift file should be self-evident. Here too `ccd_to_vax` makes a formatted read of the clock-drift file, so `Ticks` and `UT-CCD` must be in the correct columns. *It is also important that the last line of the file is a data line: there must be no blank lines at the end of the file.*

Users should note that `ccd_to_vax` makes a linear interpolation between clock-drift values to determine the UTC of individual observations. If it is unable to interpolate, it will extrapolate from the last two values in the clock-drift file. If the clock has just been reset (so that there are two very different values closely spaced in time) the extrapolation may be huge and the derived UTC greatly in error. Users are strongly advised to ensure that they make sufficient measurements of the clock drift to ensure that their timings are always interpolated. (This will also ensure that the corrected UTC will not change when a later user adds additional clock-drift timings into the clock-drift file, which otherwise would convert a previous extrapolation into an interpolation with a probably different value.)
Sample clock-drift file:

```
This file records the MJUO Photometrics clock drift
  Ticks    Approx UT date, time   UT-CCD     How determined        By whom
================================================================================
        0  1970-Jan-01 00:00:00     0.0
614999999  1989-Jun-28 01:19:59     0.0
615000000  1989-Jun-28 01:20:00   +34.       (Extrapolation)
615457177  1989-Jul-03 08:19:37   +34.       From WT's Sanyo watch WT
.
.
.
616000001  1989-Jul-10 15:06:41     0.0
625806240  1989-Oct-31 03:04:00   -01.       Petset from radio     WT & ACG
629345160  1989-Dec-11 02:06:00   -15.       From ACG's wristwatch ACG
630813600  1989-Dec-28 02:00:00   -18.87     Petset from radio     ACG
.
.
.
734699203  1993-Apr-13 11:06:00   -43.      clockread fm DS clock  JDP
735151537  1993-Apr-18 16:44:50   -47.      clockread fm DS clock  JDP
735461134  1993-Apr-22 06:44:44   -50.      ???                    MC
737520745  1993-May-16 02:51:20   -65.      clockread fm DS clock  WT
737520820  1993-May-16 02:53:40     0.      clockread fm DS clock  WT
737973963  1993-May-21 08:46:00    -3.0     clockread fm DS clock  JDP
738693669  1993-May-29 16:41:00    -9.0     clockread fm DS clock  JDP
738860141  1993-May-31 14:55:30   -11.0     clockread fm DS clock  JDP
739198078  1993-Jun-04 16:46:35   -13.0     ???                    MC
[EOF]
```

If a user has forgotten to record the value of `TICKS` it may be calculated since it is the number of seconds (*excluding* leap seconds) since 1980 January 0.0 UTC. Alternatively, a command:

$unixtime

is available which converts a user-specified value of `TICKS` into calendar date and time. (It is equivalent to the FORTH command **pdt** on the PM3000 system.) With `unixtime` is it possible to determine the required value of `TICKS` by trial and error.

2.3 $updateccd

The target-name and clock-drift files are stored on `[PHYS147]`'s disk. However, when a user creates new versions of these files, they belong to the user, not `[PHYS147]`. The command

$updateccd

will purge all older versions of the files which belong *to that particular user* (and will issue warning messages that it has been unable to delete versions belonging to other users). In this way, an individual user cannot corrupt and then delete correct files produced by other users. However `ccd_to_vax` uses the most recent version of the target-name and clock-drift files. If you corrupt these files (or find they have been corrupted) contact Dr. W. Tobin for assistance.

2.4 Tape reading

9-track CCD data tapes can be read using either (i) PHYSSA and its TSV05 tape drive in Room 817 of the Physics & Astronomy Department, or (ii) CANTVA and its tape drives at the Computer Services Centre. In both cases, the user should log on, edit the target-name and clock-drift files as necessary, and move to the subdirectory into which the data is to be written. Then on PHYSSA the command:

$allocate ms tape

allocates the tape drive to the user and gives it the logical name `tape` (on CANTVA, use **$allocate mu tape**). On PHYSSA load the tape physically and put it on line (crimping the end of the tape increases the chance of a successful load). The tape should then be mounted logically with:

$mount/foreign tape

(On CANTVA the tape must be given to the operators and use made of **$mount/foreign tape "Pls mount tape Txyz"** for the combined physical and logical mount.) If the tape reading-program aborts or is aborted with the tape away from its load point, it can be useful to use

$dismount/nounload tape

to rewind the tape to its beginning without a physical unload. The mount command can then be repeated without operator intervention.

To read the tape use either:

$ccd_to_vax

or:

$fast_ccd_to_vax

`Ccd_to_vax` will display the target-name and clock-drift files in order for the user to check that they are up to date. Prompts ask if the program should continue (default replies are indicated in square brackets, e.g. [y], and can be selected with <**CR**>).

The type of machine being used is next displayed and `ccd_to_vax` proper begins. An message may be displayed concerning recent modifications etc. to `ccd_to_vax` or `hardcopy` (Section 5). The user is asked to specify:

- THE TAPE IDENTIFICATION (e.g. T123) The tape number is not written magnetically on the tape, so this is the only way the program knows the tape number. If the number is specified incorrectly, all disk files will be inappropriately named, and all `.obslog files` will be incorrectly updated.

  The first file on the tape is then read. It contains the number of images on the tape at the time of the last `tclose`. The number is displayed. If the observer forgot to `tclose`, or if there was some write problem, the number does not correspond to the actual number of images on the tape. This number is thus only displayed for the user's information. `Ccd_to_vax` does not assume it is correct, but detects the end of the images by a double end-of-file mark or by the tape-reading subroutine returning the same header repeatedly.

- WHETHER THE IMAGES SHOULD BE WRITTEN TO DISK AND IF SO, HOW. The options are:

  1. Write to disk in FITS format, which is the default,–selected by **y** or <**CR**>. Information stored in the image-header record is decoded and transferred to appropriate FITS keywords [1]. The the file names are (for tape T123) `T123_0001.MT` for the first image on the tape, `T123_0002.MT` for the second image, and so on. (This format is compatible with the requirements of the MIDAS `INTAPE/FITS` command.) It should be noted that strictly speaking FITS is a format for 9-track $\frac{1}{2}$-inch magnetic tape only and is not defined for disk files. There are thus several FITS-like disk formats in use at observatories. The one adopted here comprises 2880-byte records and can be decoded by MIDAS, FIGARO and the FITSIO routines from HEARC (see Section 8).
  2. Write to disk in '`.PTM`' format (selected with **p**). This option is unlikely to be of interest to the ordinary user, but does provide certain facilities for debugging (see Section 9). The files written on disk have names such as `T123_001.PTM`, `T123_002.PTM` etc. The data format is more-directly related to the format of the Thomson TH 7882 CDA CCD chip. The first record of a `.PTM` file contains the undecoded header bytes; subsequent records each contain a single column's worth of data: 384 2-byte integers, padded with zeros if the full chip has not been read out. With the easy availability of the `CANTY_FITS` and `FITSIO` routines (see Section 8), users wishing to write special-purpose data handling routines are better advised to decode FITS files rather than `.PTM` ones.
  3. Write images to disk in both FITS and `.PTM` formats (selected with **b**)
  4. Do not write any images to disk (selected with **n**). However image-headers are still decoded and the tape-log and observing-log files are still created or updated. This option, coupled with a '`0`' response to the subsequent question, provides the way to create tape logs and update observation logs without having to clog up disk space with image files.

[1] The FITS specification lists surprisingly few standard keywords . The ones adopted for `ccd_to_vax` are either invented or conform to MIDAS requirements. If users require header data to be written into the `.MT` file with other keyword names they should consult Dr. W. Tobin.

- THE IMAGES WHICH SHOULD BE READ FROM TAPE The images should be specified in MIDAS `INTAPE/FITS` format in ascending numerical order e.g. **1,3,8-11,21,22,33-38** The file list can spread over 5 lines. If `0` is specified, all images will be read from the tape.

Images are now read off the tape and onto disk (or not) as specified. Image headers are decoded and two tape log files specific to the tape being read are created. They summarize information from the image headers, as described in the next section. The observation log file is updated for those targets for which an `.obslog` file has been specified in the target-name file.

Messages on the user's terminal warn if a target is not identified, if clock-drift corrections are extrapolated or if the `.obslog` file cannot be opened (presumably due to incorrect protection by the owner). However none of these events should stop the tape from being read or image data from being written to disk.

When `ccd_to_vax` has finished, the tape can be dismounted from the drive with

$dismount tape

and the tape drive can then be deallocated with

$deallocate tape

3 Tape log files

The two tape log files only contain information pertaining to the images read from tape. For the examples given below, only images 30-32 were read from tape T406.

- One file is named e.g. `T406.log` and is a 132-column ASCII file which can be examined on the user's terminal set to 132-column mode (with e.g. `c132`) or printed with commands such a **$oprint t406.log /w132** Here is an example:

```
                          Details of disk files written from Mt John CCD data transfer tape T406
                          ======================================================================

   Date and time of tape read on VAX system: 26-JUL-93 09:18:35;   Date of last software revision: 1993 May 05

File count in tape directory = 45

Files written to disk in FITS format (T406_0nnn.MT)


-------------------------------------------------------------------------------------------------------------------------------
   File      Acquisition date and time   deci-   exp. soft/w  c   r   #   #  c  r     g t Inst   p_1  p_2  p_3  p_4 Tel  Obs Airmass
                       BEGIN     END  second second          0   0 col row  b  b     n y                              Offset MJUO LST
-------------------------------------------------------------------------------------------------------------------------------

T406_0030  1993-Jul-01 17:27:02-17:28:42     0  100.0 MtJohn   0   0 384 576  1  1  100 2 Phot 187   95    1-7      1f8  JDP   3.299
           Vj     GX1+4                                                                                -DRK               368.98 23:28:17
T406_0031  1993-Jul-01 17:40:03-17:40:53     0   50.0 MtJohn   0   0 384 576  1  1  100 3 Phot 48    94    1-0      1f8  JDP   3.729
           CL'R   GX1+4                                                                                -DRK               369.40 23:40:55
T406_0032  1993-Jul-01 17:52:47-18:02:47     0  600.0 MtJohn   0   0 384 576  1  1  100 2 Phot 185   120   1-6      1f8  JDP   4.638
           Halp   GX1+4                                                                                -DRK               368.84 23:58:16

-------------------------------------------------------------------------------------------------------------------------------
```

- The other file is named e.g. `T406.logps` and is a landscape PostScript file which contains rather more header information in a more easily-read layout. This file can be printed on any PostScript printer, or (less satisfacorily) viewed on an X-11 terminal with a PostScript previewer. Here is a sample (reduced in size):

T406 University of Canterbury Te Whare Wananga O Waitaha **MOUNT JOHN UNIVERSITY OBSERVATORY** Department of Physics & Astronomy **T406**

Details of disk files written from CCD data transfer tape T406 File count in tape directory = 45

Date and time of taperead on VAX system: 26-JUL-93 09:18:35 User: [PHYS146] William Tobin Date of last software revision: 1993 May 05

Files written to disk in FITS format [T406_0nnn.MT]

File	Filter	Identification/comments Recorded acquisition date/time deci exp. soft/w c r # # c r GAIN Im Offset Inst p_1 p_2 p_3 p_4 Tel. Obs. UT DATE START FINISH secs (s) o o col row b b ty	MtJ reduction flags Julian day or MJUO Air- Heliocentric JD LST mass
T406_0030	Vj	**GX1+4** -DRK 1993-Jul-01 17:27:02-17:28:42 0 100.0 MtJohn 0 0 384 576 1 1 100 2 368.98 Phot 187 95 1-7 1f8 JDP	HJD:2449170.2329 23:28:17 3.299
T406_0031	CL'R	**GX1+4** -DRK 1993-Jul-01 17:40:03-17:40:53 0 50.0 MtJohn 0 0 384 576 1 1 100 3 369.40 Phot 48 94 1-0 1f8 JDP	HJD:2449170.2417 23:40:55 3.729
T406_0032	Halp	**GX1+4** -DRK 1993-Jul-01 17:52:47-18:02:47 0 600.0 MtJohn 0 0 384 576 1 1 100 2 368.84 Phot 185 120 1-6 1f8 JDP	HJD:2449170.2537 23:58:16 4.638

Echelle: p_1 = Cross grating; p_2 = Cross-grating micrometer setting; p_3 = Echelle tilt; p_4 = Slit width micrometer setting;
Photometer: p_1 = Guide star azimuth setting; p_2 = Guide star radius vector setting; p_3 = Filter Wheel number-Filter number;
B&C spectrograph: p_1 = Grating ruling; p_2 = Grating angle; p_3 = Collimator (focus) setting; p_4 = Real slit width;
Pentax lenses: p_1 = focal length; Bones & Ward Speckle Camera: p_1=code/short exp. in ms; p_2=Row/column sizes in hex; p_3=Indiv. image centre row offset; p_4=Indiv. image centre column offset

It should be noted that even the `.logps` file does not show all relevant image-header information. Full image-header information is available only by either (i) printing a paper copy of the image via **hardcopy** (see Section 5), or (ii) reading the FITS header with **fitsedit** (see Section 7) or some other program. For a discussion of the meaning of the various header parameters, see Section 6.

If `ccd_to_vax` aborts or is aborted before it has finished executing, the `.logps` file will not print. If the user wishes to print out this file the following word must be edited in at the end of the file:

```
showpage
```

4 Observation log files (.obslog files)

When an observation log file (recommended extension: `.obslog`) is specified in the target-name file (Section 2.1) the user should ensure that the subdirectory that will contain it has group read, write and execute protection:

$set file/protection=(group:rwe) subdirectory.dir

otherwise the `.obslog` file will not be updated if other users read tapes containing relevant images (e.g. tapes of images acquired by the Mt John technician-observers which include images from several programmes). It is not necessary for the user to create the `.obslog` files: `ccd_to_vax` will do that as necessary.

The `.obslog` files are 132-column ASCII files and can be edited and corrected with any appropriate text editor.

Here is an example (`uoc$user1:[phys146.observing_logs]gx1plus4.obslog`):

```
 GX1+4
!ID_TICKS|TAPE_FILE|RECD ACQN   BEGUN    ENDED |TELS|OBSR|EXP[s]|AIRMS| JD          |CGN|INST|FILT| P1    P2    P3    P4 |C|S
715513907 T286_0001 92-Sep-03 09:51:47-         1f8  wtjp   30.0 1.244 H2448868.9124 100 Phot V     142   220   2-6       I M
715514329 T286_0002 92-Sep-03 09:58:49-         1f8  wtjp   30.0 1.264 H2448868.9172 100 Phot V     142   220   2-6       I M
715516982 T286_0003 92-Sep-03 10:43:02-         1f8  wtjp   30.0 1.426 H2448868.9479 100 Phot V     188   9     2-6       I M
715517289 T286_0004 92-Sep-03 10:48:09-         1f8  wtjp   30.0 1.450 H2448868.9515 100 Phot V     188   41    2-6       I M
715517779 T286_0005 92-Sep-03 10:56:19-         1f8  wtjp   30.0 1.491 H2448868.9572 100 Phot V     187   95    2-6       I M
715518047 T286_0006 92-Sep-03 11:00:47-11:08:52 1f8  wtjp  485.0 1.535 H2448868.9629 100 Phot Halp  187   95    1-2       I M
715518047 T286_0008 92-Sep-03 11:00:47-11:08:52 1f8  wtjp  485.0 1.535 H2448868.9629 100 Phot Halp  187   95    1-2       I M
715518707 T286_0009 92-Sep-03 11:11:47-11:19:23 1f8  wtjp  456.0 1.599 H2448868.9704 100 Phot Halp  187   95    1-2       I M
715518707 T286_0010 92-Sep-03 11:11:47-11:19:23 1f8  wtjp  456.0 1.599 H2448868.9704 100 Phot Halp  187   95    1-2       I M
741547622 T406_0030 93-Jul-01 17:27:02-17:28:42 1f8  JDP   100.0 3.299 H2449170.2329 100 Phot Vj    187   95    1-7       I M
741548403 T406_0031 93-Jul-01 17:40:03-17:40:53 1f8  JDP    50.0 3.729 H2449170.2417 100 Phot CL'R  48    94    1-0       I M
741549167 T406_0032 93-Jul-01 17:52:47-18:02:47 1f8  JDP   600.0 4.638 H2449170.2537 100 Phot Halp  185   120   1-6       I M
[EOF]
```

The first line of the file commences with a space and is followed by the target name. The second line indicates the various data fields. Subsequent lines indicate individual science images and

begin with each image's 9-digit ID_TICKS identifier. This arrangement means that the .obslog file can sorted into temporal order with the VAX system utilities for sorting according to the ASCII collating sequence. The appropriate command is:

$sorto*bslog filename.obslog

Note that calibration images such as Th_arc for GX1+4 are *not* included in the .obslog files.

For a discussion of the meaning of most of the items in the .obslog fields see Section 6. Note also that:

- An H in front of the Julian Day indicates that it is heliocentric;
- P1, P2, P3 and P4 have to be interpreted according to the instrument used;
- the C column indicates whether the clock drift was Interpolated or Extrapolated; and
- the S column indicates whether the image was acquired with the MtJohn software extensions or with the basic Photometrics FORTH words.

However many times it is read to disk, an individual image file is entered into an .obslog file only once. (The test is based on both the value of ID_TICKS and the file name.)

5 PostScript paper prints of the images

PostScript files for producing Portrait paper prints of images can be made via

$hardcopy

Image signal values are translated to one of 32 grey levels according to one of three user-selectable options. A sample is shown on the next page, scaled to 90% of normal size.

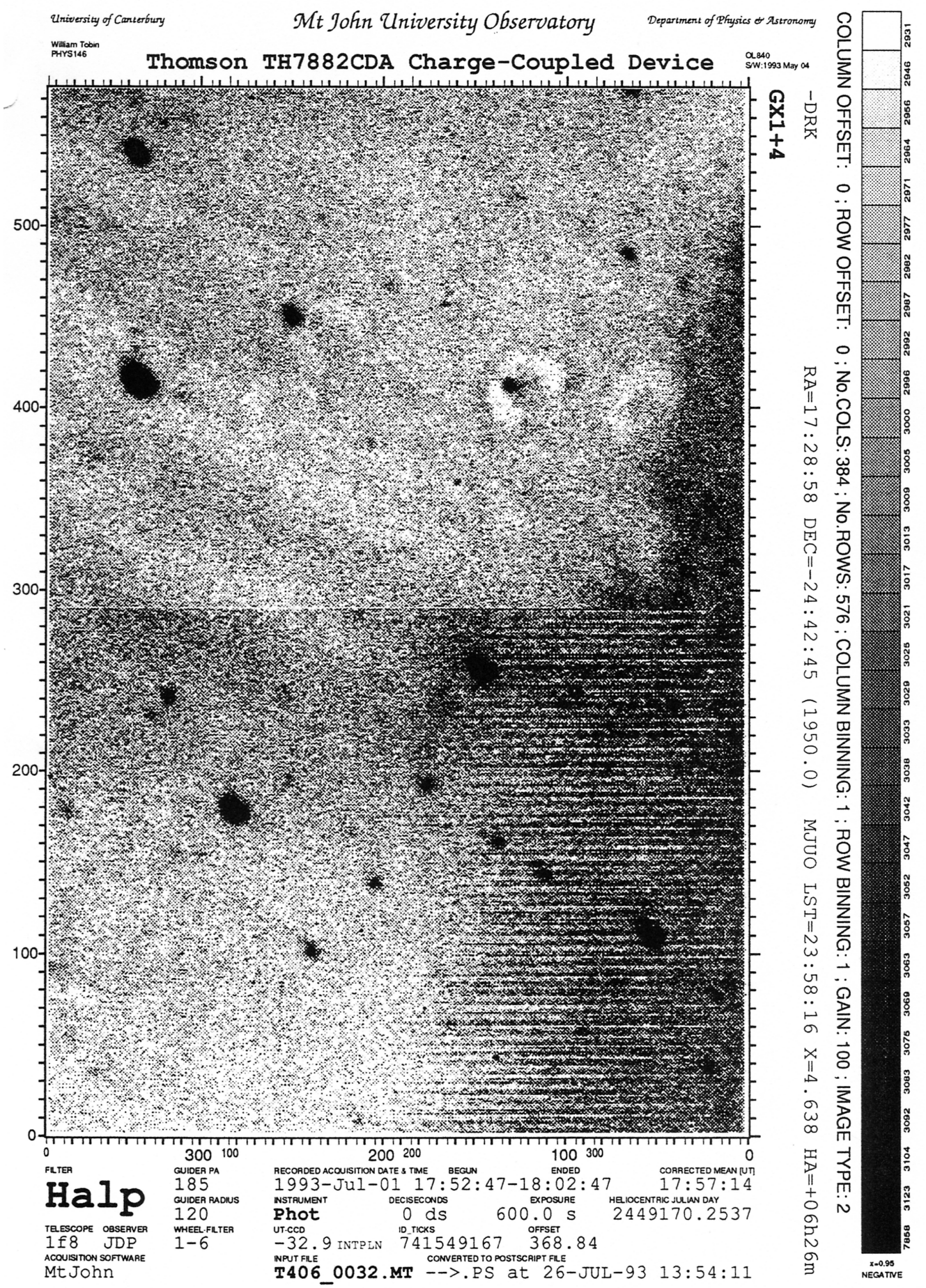
HARDCOPY works off FITS (.MT) files created with ccd_to_vax, and derives image-header information from FITS keywords. FITS files written by other software (e.g. with the MIDAS OUTTAPE/FITS command) may fail to execute or may only execute partially because of the absence of expected FITS keywords (which are not all conserved through INTAPE/FITS and OUTTAPE/FITS).

HARDCOPY asks the user to specify the .MT file, and then asks whether it is desired to use the automatic (**a**) or manual option (**m** or <**CR**>, the default).

- IN THE MANUAL OPTION the image comment field and image size are displayed to the user, who is then asked how much of the image it is desired to encode to PostScript. The whole image is encoded with **0**; smaller portions are obtained by specifying the first row and the number of rows required. Partial images may be useful for experimenting when critical greyscaling is desired because the resulting smaller PostScript files are faster to print. However the option is only useful with the **l** or **p** greyscaling options (see below); the effect of the **c** option depends on the precise pixels scaled because it involves histogram renormalization.

  Some image statistics are next displayed and the user is offered three grayscaling options:

  - CONSTANT AREAS FOR EACH GREY STEP **c** Here, a certain fraction of each image is plotted at each of the n grey levels according to $f_n \propto x^n$ and $\sum f_n = 1$, where x is specified by the user ('histogram renormalization'). This option is good at showing simultaneously both bright features without overheavy saturation and low-level features, such as a.c. pickup in backgrounds. For $x > 1$, more white is put into a positive image.


University of Canterbury
Mt John University Observatory
Department of Physics & Astronomy
William Tobin
PHYS146
Thomson TH7882CDA Charge-Coupled Device
OL840
S/W:1993 May 04
GX1+4
-DRK
RA=17:28:58 DEC=-24:42:45 (1950.0) MJUO LST=23:58:16 X=4.638 HA=+06h26m
COLUMN OFFSET: 0 ; ROW OFFSET: 0 ; No.COLS: 384 ; No.ROWS: 576 ; COLUMN BINNING: 1 ; ROW BINNING: 1 ; GAIN: 100 ; IMAGE TYPE: 2
2931 2946 2956 2964 2971 2977 2982 2987 2992 2996 3000 3005 3009 3013 3017 3021 3025 3029 3033 3038 3042 3047 3052 3057 3063 3069 3076 3083 3092 3104 3123 7858
x=0.95
NEGATIVE
0 100 200 300 400 500
0 300 100 200 200 100 300 0
FILTER
Halp
GUIDER PA
185
RECORDED ACQUISITION DATE & TIME BEGUN
1993-Jul-01 17:52:47
ENDED
-18:02:47
CORRECTED MEAN [UT]
17:57:14
GUIDER RADIUS
120
INSTRUMENT
Phot
DECISECONDS
0 ds
EXPOSURE
600.0 s
HELIOCENTRIC JULIAN DAY
2449170.2537
TELESCOPE OBSERVER
1f8 JDP
WHEEL-FILTER
1-6
UT-CCD
-32.9 INTPLN
ID_TICKS
741549167
OFFSET
368.84
ACQUISITION SOFTWARE
MtJohn
INPUT FILE
T406_0032.MT
CONVERTED TO POSTSCRIPT FILE
-->.PS at 26-JUL-93 13:54:11

  - LINEAR MAPPING OF DATA NUMBER **l** Here, the grey levels are assigned linearly between minimum and maximum ADU values specified by the user.
  - POWER-LAW MAPPING **p** Here, the user specifies an exponent n and grey levels are assigned as the $1/n$th power of the signal-level differences between user-specified minimum and maxiumum ADU levels.

  Whichever option is chosen, the user is asked whether the PostScipt image should be a positive or negative representation. Relevant parameters are then requested; in the case of the **c** option, the user is also asked if pure white is desired in the output. The ADU values corresponding to the 32 grey levels are next displayed, the PostScipt file (extension `.PS`) is created, and the user is advised of a possible print statement, e.g.

```
PostScript print statement is e.g.
 $print/queue=physps5/form=post T406_0031.PS
```

  The `.PS` file of a 384×576-pixel image occupies ∼450 kbyte.

- IN THE AUTOMATIC OPTION calibration and unidentified images are printed positive, while identified target images are printed negative. The `c` option is used with `x=0.95`; this has been found to give a usable–though not necessarily optimal–result for a wide range of calibration and astronomical CCD images.

The PostScript file (extension `.PS`) written to the user's current subdirectory can then be sent to any PostScript printer (the `/form=post` qualifier is essential, otherwise the file will print out in ASCII wasting many tens of sheets of paper).

A VMS command file is available for batch execution of the `HARDCOPY` automatic option on the images of an entire tape (e.g. all files of the form `T123_nnnn.MT`). The command:

$copyp*rocesstape

copies a file `process_tape.com` into the user's current subdirectory. The file needs to be edited: instructions for its use and submission as a batch job are contained within it.

6 Meaning of the decoded header parameters

Note that the parameters are identified by slightly different names in the tape logs, hardcopies, etc., and different names again in the actual FITS keywords, which must conform to FITS specifications. It is hoped no confusion will result.

- FILE, INPUT FILE: the name of the input FITS file.
- ID_TICKS: A 9-digit number derived from one of the time markers written in the image header, such that an image with a larger value of `ID_TICKS` was created after an image with a smaller value. (However, derived images, such as dark subtracted ones, have the same value of `ID_TICKS` as their parent, so unique identification also requires the file name.) Because `ID_TICKS` values form a chronological sequence, observation-log files can be sorted into temporal order by applying the ASCII collating sequence to the first nine characters of each line (see Section 4).
- IDENTIFICATION/COMMENTS, MTJ REDUCTION FLAGS: the contents of the first 99 bytes of the image header. The first 80 bytes are set by the observer, and the last 19 hold reduction flags `-DRK`, `NORM`, `FLAT` and `MNCL` which indicate what reductions (if any) were applied on the

PM3000 system. On the `HARDCOPY` output these fields are printed without any identifying titles.

- C_0, COLUMN OFFSET; R_0, ROW OFFSET; # COLS, NO. COLS; # ROWS, NO. ROWS; C_b, COLUMN BINNING; R_b, ROW BINNING: Photometrics parameters specifying chip-readout quantities (see Photometrics 3000 User's Manual).

- GN, GAIN, CGN: the readout-amplifier gain, `cgain`.

- TY, IMAGE TYPE: a Photometrics parameter (see Photometrics 3000 User's Manual).

- OFFSET: the value of the preflash+analogue-to-digital converter fat zero normally obtained from the central 50×50 pixels of the chip in a dark image read immediately after the saved image was read out (see UPN 5).

- RECORDED ACQUISITION DATE & TIME - START/BEGUN AND FINISH/ENDED: Recorded start and finish times for image acquisition (i.e. not corrected for clock drift). Start and finish times are both recorded only for images acquired with the `mtjohn` extension words `expose` and `readout`; other words such as `obs` or the Photometrics words `expose` & `readout` record only one or the other.

- DECISECONDS: the exposure times in deciseconds specified with words such as `obs` and `dark`. Note that the clock used for these timing runs ∼4% fast (See UPN 7).

- EXPOSURE (S): The exposure time in seconds calculated either as the interval between the recorded start and finish aquisition times (in which case it will be accurate to a very small fraction of a second, since the `mtjohn expose` & `readout` commands are synchronised to the seconds ticks of the Interrupt Service Register—see UPN 7), or from the value of `deciseconds` (in which case it will be about 4% in error). **If exposure times or durations are required with critical accuracy, users should only use `expose` and `readout`.**

- UT-CCD: the clock correction in seconds for the time of mid exposure, followed by an indication whether it is interpolated or extrapolated.

- CORRECTED MEAN [UT]: the UTC time of mid exposure calculated from the recorded start and/or finish times and/or the exposure, corrected for the clock drift.

- MJUO LST: the corresponding local sidereal time at Mt John.

- RA; DEC; ( ): Right ascension and declination of the target (if identified) at the equinox (assumed equal to the epoch) given in the target name file.

- HA: the hour angle of the target at mid observation, calculated from the local sideral time and the target coordinates precessed rigorously to the epoch and equinox of mid observation (based on appendix I.3 of Henden, A.A., & Kaitchuk, R.H., 'Astronomical Photometry,' van Nostrand Reinhold, 1982).

- AIRMASS, X: The average airmass appropriate for photometric reductions calculated according to P.B. Stetson's prescription [*Highlights of Astronomy* **8,** 635 (1989)]:

$$< X >= \frac{1}{6}\left[X(t_{begin}) + 4 \times X(t_{mid}) + X(t_{end})\right]$$

where t_{begin} and t_{end} are the times at the beginning and end of the exposure and t_{mid} is the time at its middle. The expression for airmass is taken from Young, A.T., *Methods of Experimental Physics* **12a,** p.152 (Eqn. 3.1.43):

$$X(t) = \sec z(t) \times (1 - 0.0012 \times (\sec^2 z(t) - 1))$$

where $z(t)$ is the *true* zenith distance at time t.

- JULIAN DAY OR HELIOCENTRIC JULIAN DAY: the Julian day of mid observation, or, if target coordinates are available, the heliocentric Julian day [calculated according to Meeus, J., 'Astronomical Formulae for Calculators' 4th edition, Willmann-Bell, Inc., Fairfax, (1988) Ch. 18 for the radius vector, R, and Landolt, A.U., & Blondeau, K.L., *Publ. Astron. Soc. Pacific* **84,** p.784 (1972) for the correction].

- TEL., TELESCOPE: the telescope (and possibly focal ratio) used.

- FILTER: the filter used.

- INST., INSTRUMENT: the instrument used. Besides the filter, there cam be up to four parameters associated with each instrument. They are stored as either ASCII characters or real numbers in 4-byte header fields known as `p_1`, `p_2`, `p_3` and `p_4`. On the tape logs and observation logs the parameters are represented as characters or numbers as appropriate, but the user must work out what each parameter refers to (a key is printed at the bottom of the last page of the `.logps` files). The parameter meanings are, however, interpreted on `HARDCOPY` output.

- OBS., OBSERVER: up to 4 ASCII characters identifying the observer(s).

- S/W, ACQUISITION SOFTWARE: `MtJohn` if the image was acquired with the `mtjohn` extensions, `Ptmrcs` if not.

In addition, the tape log and `.PS` files print information such as:

- the user code and process name,

- the PostScript printer used,

- the date of the most recent revision of the `HARDCOPY` or `ccd_to_vax` software (do not confuse with the image-header software parameter),

- the local date and time when the software was run.

7 Other commands

Other CCD-related commands are:

$fitse*dit

(written by Karen Pollard) which allows the user to read and edit the ASCII header portion of a FITS file. When the command is invoked, the user is warned that premature exit (e.g. with

Ctrl-C) leaves behind various temporary files which must be deleted before `fitsedit` can be used again.

$ccdo*verlay
which produces a PostScript file `OVERLAY.PS` for a mylar sky-survey overlay for use in selection of guide stars for the CCD photometer head and for determination of guider radius and azimuth values.

$upn
which displays a list of available *Use & Performance Notes.*

$ccdp*ublications
which displays a list of publications of whatever nature which have derived from the Mt John CCD projet. Users are requested to inform Dr. Tobin of their CCD publications *once they have appeared in print* so that the list can be kept up to date.

$copyccdt*argets and **$copyccdcd**
which copy the target-name and clock-drift files into the user's current subdirectory.

$copyccdh*elp, **$copyupn** and **$copyccdp*ublications**
which copy the help, Use & Performance Note and publications files into the user's current subdirectory.

$old_ccd_to_vax
which invokes the previous-to-current version of `ccd_to_vax`. This is not normally implemented, but may be available when modifications have recently been made to `ccd_to_vax`. The message displayed when `ccd_to_vax` and `hardcopy` are run will advise users when `old_ccd_to_vax` is available.

8 FITSIO and CANTY_FITS

The High Energy Astrophysics Science Archive Research Center (HEARSC) at the Goddard Space Flight Center has produced a set of Fortran subroutines for reading and writing FITS files (see Pence, W.D., 'FITSIO and FITS file utility software,' In *Astronomical data analysis software and Systems I,* Astronomical Society of the Pacific Conference Series **25,** Worrall, D.M., Biemesderfer, C., Barnes, J. (Eds.) p.22; this reference also indicates how to obtain the subroutines and instructions via `ftp`). `Ccd_to_vax` does not use these routines for writing its `.MT` files, but `HARDCOPY` does use them for reading the `.MT` files. The relevant files FITSIO files required by `HARDCOPY` have been extracted and put in a much shorter file:

`uoc$user1:[phys147.ccd]canty_fits.for`

Associated with this are two macro files:

`uoc$user1:[phys147.ccd]vmsieeed.mac`

`uoc$user1:[phys147.ccd]vmsieeer.mac`

Compiled versions:

`uoc$user1:[phys147.ccd]canty_fits.obj`

`uoc$user1:[phys147.ccd]vmsieeed.obj`

`uoc$user1:[phys147.ccd]vmsieeer.obj`

are also maintained on disk and can be employed by users who wish to link these routines into their own programs. (When the Alpha system becomes available, additional macro and object files will be necessary.)

9 System engineering notes

The following remarks are provided for those implementing this suite of programs at other sites.

An attempt has been made to make the Fortran source and VMS command files both self-documenting and self-explanatory, though some knowledge of Fortran and VMS is required. A file `REQUIRED_FILES.README` lists all the files needed to implement the software in Christchurch and provides a guide to what will be necessary at other sites.

All source files will need to be complied and linked to produce executable modules. Many command files will need to have Christchurch disk and directory names changed to local ones. A command file `CCDLINK.COM` is available to simplify linking.

Certain variables etc. in the `ccd_to_vax` and `HARDCOPY` Fortran, while not user specifiable, are specific to the local VAX cluster. They have all been put into a self-documented include file `CCD_INCLUDE.INC` so that `ccd_to_vax.for` and `hardcopy.for` do not need to be re-edited for local requirements every time new versions are distributed. It is suggested that once debugged, any other site-specific modifications be implemented into the master code held in Christchurch (contact Dr. W. Tobin).

`Ccd_to_vax` and `HARDCOPY` include certain features to help in debugging. `HARDCOPY` can display messages that permit the user to monitor the program's progress; for this, the logical variable `debug` in the source code must be set to `.true.` and the whole code recompiled and relinked. `Ccd_to_vax` has a wider range of debugging features. Each use of `ccd_to_vax` is recorded in a usage file which can be examined to check that the code is being run successfully by users. Instead of reading from 9-track tape, which is time consuming during code development, `ccd_to_vax` can be made to read from disk. For this, relevant images must be written to disk in `.PTM` format in the standard way, and then renamed to have names of the form `Dxyx.PTM` (where `D` stands for 'debug' and `xyx` can be any three characters). These files can now be used for input image data (one per execution of `ccd_to_vax`) by specifying `Dxyx` as the tape to be read. `Ccd_to_vax` also then displays numerous messages reporting progress as the code executes.

The target-name and clock-drift files need the following ACLs when the files are held by user `[PHYS,PHYS147]`:

```
(IDENTIFIER=[PHYS,PHYS147],ACCESS=READ+WRITE+EXECUTE+DELETE+CONTROL)
```

University of Canterbury Department of Physics & Astronomy

Mt John University Observatory

Mt John Photometrics CCD System

Use and Performance Note
Number 14

FORTH COMMANDS
IMPLEMENTED BY
THE FILE jdp

John D. Pritchard

1993 October 12

These Notes are intended for guidance only: individual observers have the sole responsible for the integrity of their own data. Users of the CCD system are encouraged to summarize the performance that they obtain in a Note in this series. Contact Dr. W. Tobin to be allocated a series number.

Forth Commands implemented by file *jdp*

The

Magellanic Cloud Eclipsing Binary Star Systems Program.

JOHN D. PRITCHARD.

Version 1.1

The file *jdp* has been developed to standardise, optimise and ease the obsevation procedure for the *Magellanic Cloud Eclipsing Binaries* (MCEB) program which forms the basis of my Ph.D. thesis work. The following documentaion outlines what immediately happens and the new words available when the file is loaded, and the desired observation procedure for the MCEB project.

If any problems arise J.D. Pritchard should be notified. For help JDP can be reached on;

0-3-343 3881	Home phone number (Before 11:00 pm preferably, but should a problem mean loss of perfect conditions call at any time.)
0-3-364 2539	Astronomy Students Room, UofC.

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One Initialisation:

The file *jdp* is loaded by typing

```
\lf jdp
```

after one has loaded file *mtjohn* ie

```
\lf mtjohn
```

ie full load sequence from a hard reset is:

```
>bw

>25 load

\lf mtjohn

\lf jdp
```

Loading *jdp* automatically sets several parameters. These are...

1) *JDP* is loaded into the *Observer_name* field.
2) *cgain* is set to 100.
3) *Telescope* is set to *1f8*
4) *Instrument* is set to Photometer.
5) The flags allowing writing to tape and to disk are set (ie. `+twrite` and `+write`)
6) Printer logging is switched off (`apxff`). This is necessary since the printer logging interferes in some unknown way with some of the basic and important words. However many of these words have an alternative method of logging built in. The observer can switch the printer logging on from time to time (`apon`) in order to keep a log of work not covered by logging built into specific words, but must switch it back off (`apoff`) in order for all of the words to perform as they are intended. The main bug seems to be with `yes/no` prompts, this will give you a general outline of which of the words that follow can and can't be used while the printer is logging (ie. `apon`).

Note that any observer other than JDP will need to set the *Observer_name* field (`set_observer`).

At the completion of loading, the observer is prompted (`yes/no`) as to whether or not to initialise the caches. If `y` then the word `setcaches` will be invoked.

```
setcaches   ( -- )
```

This word acquires a BIAS frame in the `fullf` chip format (ie. 384x576, see §2.5) in cache 2. This BIAS frame is then copied into caches 3 through 8 and 10 through 13. An `80fmtc` chip format (80x80, see §2.5) BIAS is obtained in Cache 9. The caches are displayed (`caches`) and then the current cache is set to cache 2. This concludes initialisation. (Unless one needs to set *Observer_name*).

Thus set, the caches are intended to be used as follows.

cache 1	Inaccessible
cache 2	`DARK`
cache 3	`u` Exposures
cache 4	`v` Exposures
cache 5	`b` Exposures
cache 6	`y` Exposures
cache 7	`Ic` Exposures
cache 8	`Vj` Exposures
cache 9	Focusing Exposures
cache 10	1st of multiple exposures that will subsequently be medianed
cache 11	2nd of multiple exposures that will subsequently be medianed
cache 12	3rd of multiple exposures that will subsequently be medianed
cache 13	Ocassional `HALP` (H_α) exposures, otherwise spare

Most of the commands that follow have been designed around this cache structure, thus if it does not exist there are likely to be problems.

The cache structure can at any time be reinitialised simply by submitting the word **`setcaches`**, ie it is not necessary to reload file *jdp* to set the caches. On the other hand, having set the caches once, should one need to reload file *jdp* one need not necessarily reset the caches, providing the cache structure still exists, of course.

Two New Words:

A full list of the new words available after loading file *jdp* is given in the index. The following outlines the usage of the more important and useful of these words. The more important of these words are described in some detail in terms of their constituant words.

2.1 Darks

darks (--)

When **darks** is invoked the following takes place. The HDS terminal is cleared (**vte**), The chip format is set to **fullf** if is not already, and the *cgain* is set to 100 if it is not already (**f100c**). Then three 100 decisecond DARK frames are obtained in caches 10, 11 & 12 (**100 dark**), each frame is displayed on the monitor (**qshow**). Then a series of **yes/no** prompts lead the observer through computing the median of the three DARKS (which is installed into cache 2), and then saving this median frame to Winchester Disk and/or tape (**jpmed?**). A *tcomment* can be added to the frame during the process if desired. Finally the screen is dumped to the printer (**vtp**).

Note: The observer must ensure that an appropriate dark is cache 2 since most of the observing words that follow depend on that being the case.

The DARK should be saved as part of nights data set as it could be handy for dealing with problems that may arise from gear failures (eg. the flash-ring) that may occur.

2.2 Flat–fields

uflats (t --)
vflats (t --)
bflats (t --)
yflats (t --)
Icflats (t --)
Vjflats (t --)
Haflats (t --)

These words are used for obtaining flat–field exposures in the respective colours. The steps involved in each word are as follows. The HDS terminal is cleared and six carriage-returns (**vtecr**) are used to start printout at line seven. Then a phrase with the integration time and the filter used followed immediately by "flats" eg.

```
1200 uflats
```

The chip format is set to **fullf** if is not already, and the *cgain* is set to 100 if it is not already. Three **t** decisecond **obs** exposures are obtained in caches 10, 11 & 12. Each frame has the string "dome_flat" written to the *comment* field (**flatname**), has the DARK in cache 2 subtracted (**2 -dark**), is displayed (**qshow**) and then is normalised to a mean of 10,000 (**normalise**). A **yes/no** prompt checks that the observer wants the median of the three FLATS

computed (which is installed into the cache reserved for that filter, (see §1). At this stage the screen is dumped to the printer (`vtp`) and the screen is cleared again (`vte`). The `yes/no` prompts for saving this median frame to Winchester Disk and/or tape follow. Again a *tcomment* can be added to the frame during the process if desired (`jpmed?`). Finally the screen is again dumped to the printer (`vtp`).

Notes: These medianed `FLAT`s need to be saved to tape as part of a night's data set but the individual `FLAT`s before medianing are not needed.

A *tcomment* such as `median of 3x6700 uflats` is useful.

Reminder, `u` exposures go into cache 3, `v` into cache 4, `b` into cache 5, `y` into cache 6, `Ic` into cache 7, `Vj` into cache 8 and `HALP` into cache 13.

Appropriate exposure times for the various filters loaded in filter wheel 1 for dome_flats are as follows:

Filter	Deci-secs	Lamp	ND filter
`u`	6700	1200 W	None
`v`	450	1200 W	None
`b`	570	1200 W	1 x 0.9
`y`	410	1200 W	2 x 0.9
`Vj`	120	1200 W	2 x 0.9
`HALP`	360	1200 W	2 x 0.9
`I`	1000	5 W	None

Though one should make adjustments as neccessary to ensure that the normalisation factor is close to 1·00. For the purposes of determining the appropriate exposure time, the word `normobs` is useful.

```
normobs    ( t --)
```

This word simply takes a `t` deicsecond `obs` exposure (in the current filter), subtracts the `DARK` in cache 2 (`2 -dark`), normalises the frame to 10,000 (`normalise`) and then displays the result (`qshow`).

2.3 Focusing

A specific "focus-star" (FS) for each of the Magellanic clouds (λ^1 Tucano for the LMC and δ Dorado for the SMC) has been established. Once the appropriate FS has been obtained targets are easily obtained given well known offsets. However, it would appear that both of these are probably too bright for focusing, particularly in I and certainly with the Clearglass plate. Also the Clearglass plate can be used to focus with integration times of the order of 100 deciseconds using the brighter field stars in the target field is possible on reasonable nights.

For the actual process of focusing several new words have been defined,

```
      jpfocus   ( hunt_time row_center col_center -- ),
     jpfocusp   ( hunt_time row_center col_center -- ),
         jpfc   ( hunt_time -- ),
        jpfcp   ( hunt_time -- ),
and     hvfoc   ( hunt_time -- )
```

All of these words automatically set the current cache to 9. To reduce readout times they examine an 80x80 pixel region only and set the *cgain* to 0.

For `jpfocus` and `jpfocusp` the central point (`row_center`,`col_center`) of this region can be specified anywhere on the chip. For `jpfc` and `jpfcp` the region is the chip centre. For `hvfoc` the region is centred on the selected target (See § 2.3.1 Selecting Targets). All of these words are defined in terms of the word `hunt` and are thus stopped by entering `ctrl-z`.

In addition, the value, the row and the col of the brightest pixel within the central 40x40 pixel region of the readout area is displayed on the terminal.

`jpfocusp` and `jpfcp` are the same as `jpfocus` and `jpfc` respectively, except that after each exposure a plot is made of the row and column of the brightest pixel within the central 40x40 pixel region of the readout area. These plots are intended to give the observer a feel for the quality of the focus. Obviously these plots slow down the iteration rate, so the words `jpfocusp` and `jpfcp` are intended to be used for "fine tuning" the focus.

These features are added in by the words `jphunt` and `jphuntp`, which are based on `hunt`.

Note: All focusing and field acquisition/positioning should be done with the `Clearglass` plate.

2.4 Observing the Targets

2.4.1 Selecting Targets

Each target has (or at least should have) defined a word (hereafter referred to as the target-words)

```
hv_00982    ( -- )
hv_01620    ( -- )
hv_02241    ( -- )
hv_02401    ( -- )
   GX1+4    ( -- )
```

Entering the appropriate target-word for a given target will set the exposure times for each colour, move the Offset-Guider-Camera to the appropriate settings (*azimuth* and *radius*) and set the *target_name* appropriately. (These words also load positional data on several stars in the field, one of which is of course the target, into the vectors *xpos* and *ypos*. These data are used in several of the words described below eg **transfer**, **hvipos**.)

Each target has a specific position on the CCD, the so-called Optimum-Target-Position (OTP). The observer should attempt to maintain the target at this position (±~3 pixels) for all observations. Due to what is assumed to be the variable angle of mounting of the individual filters each filter images to a slightly different position on the CCD. The best policy is to postion as best as possible the target in **Clearglass** and then maintain that position, ie. do NOT bother to try and center each filter individually, as long as all the **u** exposures have the same offset as each other, all the **v** exposures have the same offset as each other...

2.4.2 Making Observations

The following words have been designed to ease and standardise observations:

```
  hvue    ( -- )
  hvve    ( -- )
  hvbe    ( -- )
  hvye    ( -- )
 hvIce    ( -- )
 hvVje    ( -- )
 jpexp'   ( t -- )
```

Each of the **hv*e** words sets the appropriate filter and cache (see §1) and then calls **jpexp** submitting the appropriate exposure duration in seconds (**t**). The exposure times for the various filters are loaded by the target words (§2·4·1) into the array *exptimes*. The values in this array can be examined with the word **expts**.

The word `jpexp` procedes as follows. The HDS terminal is cleared (`vte`). Then a phrase describing the exposure is displayed, eg

```
"1200 sec exposure in u   Target id: HV_00982"
```

The full chip format and 100 *cgain* are set automatically. A `t` second exposure (using `expose` and `readout` as against `obs`) is made, during the exposure a second by second countdown is displayed. Upon completion of the exposure, the `DARK` in cache 2 is subtracted (`2 -dark`), the frame is displayed (`qshow`) and the row and column of the brightest pixel within the 20x20 box centered on the targets position, and its ADU value are displayed (`hvmax`). Then the `stats` of the 20x20 box centered on the targets position (`hvstats`) and differential photometry of the target and two comparisons (`hvdphot`) are displayed. The save-to-disk-and/or-tape sequence (`2dort?`) follows. Finally the screen is dumped to the printer (`vtp`).

Notes: It would seem advisable to always save to disk before writing to tape since if the tape write fails it can sometimes corrupt the data. Thus if something fails in the prompting and the frame does not get written to disk, then one should probably input `n` at the "Write to tape" `yes/no` prompt and then resubmit the word `2dort?` in order to ensure the frame is written to disk first.

JDP tries to maintain a one-to-one relationship between the files on the disk and the files on the current tape. This makes writing the files to a new tape should a problem arise with the current tape quite simple. Indeed some words have been defined to expediate this very process.

2.5 Other Useful words

A number of other useful words have been defined. The usage and performance of some of them are summarised in the following.

2dort? (--),	A series of **yes/no** prompts that leads the observer through saving the current frame to Winchester disk and/or tape. A *tcomment* can be added during the word. A variable *dd#* keeps track of the last file number that was used and offers that number plus one as a default file number the next time **2dort?** is invoked.
3phot (--),	Computes differential magnitudes between the target and three first two comparison stars (defined in the target-word). This routine can easily be confused by cosmic rays within 10 pixels of any of the three stars concerned so don't believe everything you see.
80fmt (row col --),	sets the chip read out format to an 80x80 square centered on the coordinates (**row**,**col**), with 1 1 binning
acur (r c --),	sets the graphics cursor to the co-ordinates (r,c). Note that **qcur**(**dr dc** --) moves the graphics by an amount (-**dr**,**dc**).
biass (n --),	Simply does **n BIAS** exposures. Useful at start of night when it may take of the order of 20 **BIAS** exposures for the CCD to stablize.
cc (--),	Shorthand for **clockread**.
d2hc (ds df ts --),	Copies disk files **ds** to **df** to the hc tape starting at file number **ts**. The current cache is used.
d2mt (ds df --),	Copies disk files **ds** to **df** to the tape. The current cache is used.
f100c (--),	insures that the chip format is **full** and that the *cgain* is 100.
full (--),	sets the chip read out format to the full chip, with 1 1 binning, ie. **0 0 384 576 1 1 !fmt**
hc2d (ts tf ds --),	Copies tape files **ts** to **tf** to the disk starting at file number **ds**. The cuurent cache is used.
hvbox (--),	displays a 15x15 pixel box at the Optimum-Target-Position
hvdphot (--),	computes the differential magnitude between the target and the stars 2 and 3 specified in the target-word. Individual magnitudes are computed by **hvimag**, and the computed differential magnitudes displayed.

\hvbox	Displays a 15x15 pixel box centered on the "Optimum-Target-Position" (OTP)
\100 jphunt	Obtain the GX1+4 field. Don't worry too much about getting GX1+4 in the dead center of the 15x15 pixel box at this stage. (**jphunt** is essentially the same as the basic **hunt** word apart from one or two incidental aspects)This word automatically sets the *cgain* to 0. The current cache is used for these exposures
\100 r c jpfocusp	Focus the telescope using the row and column plots or the "maximum pixel value" as guides. (**r**,**c**) are the co-ordinates of the bright field star to be used for focusing. This word automatically sets the *cgain* to 0 and the CCD chip read-out format to 80x80 pixels, centered on (**r**,**c**). Cache 8 is used for these exposures
\100 hvfoc	After focusing check exact positioning of field. This word will readout at the 80x80 pixel region centred on the Optimum-Target-Position, therefore guide target to center of the central 15x15 box. The terminal printout can also be used as a guide, obviously (?) one is aiming to put the brightest pixel at the co-ordinates (40,40)
\halpa	Sety the filter to **HALP** for observations
\13 ci	Use cache 13 for obsevations
\600 jpexp	Obtain a 600 second exposure. **jpexp** will automatically set the *cgain* to 100 and the CCD chip read-out format to the full chip. A second by second coutdown of the exposure is displayed. **Ctrl-z** will quit the word, but the observer must then use the word **readout** to stop the exosure. Once the exposure is completed a series of statistics will be displayed as well as the differential photometry. Finally a series of prompts leads the observer through saving the frame to disk and/or tape. Given the recent problems experienced with the tape drive, saving to disk before saving to tape is recomended
\13 14 transfer	transfer 61x61 pixel "cutouts" centered on the target, check and comparison stars to a separate frame (and **qshow**). This cutout image is useful simply for checking the focus, but by no means necessary
\hvmaxplot	Check the focus by ploting the image profile
\600 jpexp	Next observation
⋮	
\360 vjflats	Obtain end of run dome_flats if necessary

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Three Procedure

Procedural matters generally fall into one of two categories, nightly procedures or those more applicable to a given run as a whole. The latter is most easily dealt with first since there are in fact few of them. Indeed I can think of only one, namely measurement of the CCD Clock-Drift. These measurements should certainly be made at the start and end of a run, and possible every 5 days or so during a run. When measuring the Clock-Drift several pieces of data are required:

(1) The "TICKS" value
(2) UTC date and time of measurement
(3) UTC - CCD
(4) A note discribing the UTC reference used

3.1 Nightly procedures for observations of MCEBs

The following is an idealised typical nights observations of, for example HV982, starting from a hard reset.

`>bw`	
`>25 load`	
`\lf mtjohn`	
`\lf jdp`	Be sure to set the caches
`\set_observer`	Change observers initials appropriately
`\hv_00982`	Set the target for the nights observations
`\ddatainit`	Initialise the Winchester disk
`\newtape`	Initialise the tape
`\topen`	Open the tape
`\20 biass`	To "stabilise" the CCD
`\darks`	Obtain 3x100 deci-sec dark frames
`\140 vjflats`	Obtain 3x140 deci-sec dome_flat frames in `vj`
`\clearglass`	Set the filter to the `clearglass` plate for focusing and field positioning
`\100 jpfc`	After driving the telescope to the FS (or some other suitable focus star) or indeed the field, focus the telescope. (Remember `jpfc` focuses on the central 80x80 pixel region of the chip)
`\100 jpfcp`	Fine tune the focus using the row and column plots. Alternatively use `jpfocus` and/or `jpfocusp`
`\100 hvfoc`	After focusing, drive telescope to target and check exact positioning of field. This command will readout at the 80x80 pixel region centred on the Optimum-Target-Position, therefore guide target to center of the central 15x15 box

\hvvje	Begin observations
\8 14 transfer	transfer the target, check and comparison stars to a separate frame (and **qshow**)
\hvmaxplot	Check the focus by ploting the image profile
\hvvje	Next observation
⋮	
\140 vjflats	Obtain end of run dome_flats

3.2 Observations of GX1+4

In order to obtain meaningful (if low accuracy) online differential photometry at the telescope for the object GX1+4, it is essential that all observers who will be making observations of this object do so in as standard a way as possible. With this in mind the following procedure has been devised for these observations. (The following assumes that the observer is begining with a hard reset. Obviously several of the initial steps can be omitted if the PM3000 has already been reset and booted and FORTH and the file *mtjohn* have been loaded as well as the commands refering to the disk and tapes.)

>bw

>25 load

\lf mtjohn

\lf jdp	Be sure to set the caches, ie. answer y to the **setcaches?** prompt
\set_observer	Set observers initials appropriately
\GX1+4	This so-called "target-word" automatically sets the *target_name* field (to GX1+4), sets the *radius* and *azimuth* of the photometer head offset guide camera (to 82 and 135 respectively) and loads positional data on GX1+4 and 5 other stars in the field
\ddatainit	Initialise the Winchester disk
\newtape	Initialise the tape
\topen	Open the tape
\20 biass	To "stabilise" the CCD
\darks	Obtain 3x100 deci-sec dark frames. The indiviual **DARK** frames are stored in caches 10, 11 and 12 and the median is put in cache 2
\360 haflats	Obtain 3x360 deci-sec dome_flat frames in **HALP**. The indiviual flat field frames are stored in caches 10, 11 and 12 and the median is put in cache 13. 360 deci-sec should be used only as a guide. The observer should select a time appropriately such that the normalisation constant is within 0.05 of 1.00. Note, Use the 1200W lamp with 2 sheets of 0.9 ND filter
\clearglass	Set the filter to the **clearglass** plate for focusing and field positioning

hvi2dg (*No --),
Perfoms the *mtjohn* word **2dg** centered on the brightest pixel witin 10 pixels of star number ***No**. The word **hv2dg** defaults to star number 1, ie. the target.

hvibox (*No --),
Displays a 20x20 pixel box centered on star number ***No**. The word **hvbox** defaults to star number 1, ie. the target.

hvimag (*No --),
Computes the magitude of star number ***No** (as defined in the target-word). The magnitude is computed by counting the ADU in the (2**halfbox**)x(2**halfbox**) pixel box centered on the brightest pixel within 10 pixels of the Optimum-Star-Positions. Sky subtraction is based on the **border** pixel annulus. (**halfbox** and **border** are variables which can be arbitarily set (eg `15 halfbox !`)to suit seeing conditioins on a given night - default values are 10 and 5 respectively). Boxes are displayed to indicate the "counting-box" and "sky-annulus".

hvimax (*No --),
Displays the ADU value and row and column of the brightest pixel within the 20x20 pixel box centered on star number ***No**. The word **hvmax** defaults to star number 1, ie. the target.

hvimaxplot (*No --),
plots the row and column of the brightest pixel found by **hvimax**. This is most useful on a "transfered" frame (see **transfer** below) since the graph width is only 60 pixels wide, not 384! Note that the column plot shows the target, not star number ***No** (unless of course ***No** = 1). **hvmaxplot** does the plots for the target object. Also, **hvimaxplot2** plots the row and column of star number ***No** but has do make three plots to do so. It. is therefore a little slower.

hvipos (*No -- r c)
Puts the position (r,c) (as defined in the target word) of star number ***No** on the stack. The word **hvpos** defaults to star number 1, ie. the target.

hviqs (*No --),
qshows the frame in the current cache but with *GMAX* and *GMIN* determined based on the 20x20 pixel box centered on star number ***No** (rather than the center of the frame) The word **hvqs** defaults to star number 1, ie. the target.

hvistats (*No --),
Displays the **stats** statistics of the 20x20 pixel box centered on star number ***No**. The word **hvstats** defaults to star number 1, ie. the target.

hvizoom	**(rs cs *No --),**	Displays the frame in the current cache at zoom factors (**rs**,**cs**) centered on star number ***No**. The word **hvzoom** defaults to star number 1, ie. the target.
hvmag	**(--),**	computes the magnitude of the Target object. See **hvimag**.
hvmax	**(--),**	computes the location and ADU value of the brightest pixel within the 20x20 box centered on the Optimum-Target-Position and displays the result.
hvstats	**(--),**	computes the statistics centred on the Optimum-Target-Position
mmag	**(--),**	computes the magnitude of the "selected" object. The "counting-box is centered on the brightest pixel within 10 pixels of the current cursor position, which can of course be selected with the mouse, **sw**, **sb**, **qcur**, or **acur**.
mt2d	**(ts tf ds --),**	Copies tape files **ts** to **tf** to the disk starting at file number **ds**. The cuurent cache is used.
obox	**(s --),**	displays a **sxs** pixel box at the current cursor location. ie at the CENTER of the frame unless the mouse or word **qcur** has been used since the last ci specification.
obox@rc	**(b r c --),**	Displays a **bxb** box at (**r**,**c**).
prc	**(row col --),**	plots the row **row** and then overplots the column **col**.
raaz	**(ra az --),**	Sets the photometer head offset-guider-camera to *Radius* = **ra** and *Azimuth* = **az**. (Also defined are the words **ra(ra --)** and **az(az --)** - a little confusing I know but I think their meaning is pretty obvious).
topen	**(--),**	The same word as defined in file *mtjohn* except the printer logging is enabled and then disabled in order to keep a log of all tape opertations. **oldtopen** is available as the *mtjohn* version. Similarly for **tclose**, **oldtclose**, **tw**, and **oldtw**.
transfer	**(from to --),**	transfers data from cache **from** to cache **to** in 61x61 pixel sections centered on the postions of up to 7 stars as specified in the target words, ie. **hv_00982** etc. The word **transferq** does the same thing except it **qshows** upon completion of the **transfer**.
xymaxs	**(row col hb --),**	computes the ADU value and position of the brightest pixel within the (2x**hb**)x(2x**hb**) pixel box centered on the co-ordinates (**row**,**col**).

the PM3000 has already been reset and booted and FORTH and the file *mtjohn* have been loaded as well as the commands refering to the disk and tapes.)

```
>bw
>25 load
\lf mtjohn
```

`\lf jdp`	Be sure to set the caches, ie. answer `y` to the `setcaches?` prompt. Note that this will distroy any data already in memory
`\set_observer`	Set observers initials appropriately
`\GX1+4`	This so-called "target-word" automatically sets the *target_name* field (to GX1+4), sets the *radius* and *azimuth* of the photometer head offset guide camera (to 82 and 135 respectively) and loads positional data on GX1+4 and 5 other stars in the field
`\ddatainit`	Initialise the Winchester disk
`\newtape`	Initialise the tape
`\topen`	Open the tape
`\20 biass`	To "stabilise" the CCD
`\darks`	Obtain 3x100 deci-sec dark frames. The indiviual DARK frames are stored in caches 10, 11 and 12 and the median is put in cache 2.
`\360 haflats`	Obtain 3x360 deci-sec dome_flat frames in HALP. The indiviual flat field frames are stored in caches 10, 11 and 12 and the median is put in cache 13. 360 deci-sec should be used only as a guide. The observer should select a time appropriately such that the normalisation constant is within 0.05 of 1.00. Note, Use the 1200W lamp with 2 sheets of 0.9 ND filter.
`\clearglass`	Set the filter to the `clearglass` plate for focusing and field positioning
`\hvbox`	Displays a 15x15 pixel box centered on the "Optimum-Target-Position" (OTP).
`\100 jphunt`	Obtain the GX1+4 field. Don't worry too much about getting GX1+4 in the dead center of the 15x15 pixel box at this stage. (`jphunt` is essentially the same as the basic `hunt` word apart from one or two incidental aspects)This word automatically sets the *cgain* to 0. The current cache is used for these exposures
`\100 r c jpfocusp`	Focus the telescope using the row and column plots or the "maximum pixel value" as guides. (`r`,`c`) are the co-ordinates of the bright field star to be used for focusing. This word automatically sets the *cgain* to 0 and the CCD chip read-out format to 80x80 pixels, centered on (`r`,`c`). Cache 8 is used for these exposures

\100 hvfoc	After focusing check exact positioning of field. This word will readout at the 80x80 pixel region centred on the Optimum-Target-Position, therefore guide target to center of the central 15x15 box. The terminal printout can also be used as a guide, obviously (?) one is aiming to put the brightest pixel at the co-ordinates (40,40)
\halpa	Sety the filter to **HALP** for observations
\13 ci	Use cache 13 for obsevations
\600 jpexp	Obtain a 600 second exposure. **jpexp** will automatically set the *cgain* to 100 and the CCD chip read-out format to the full chip. A second by second coutdown of the exposure is displayed. `Ctrl-z` will quit the word, but the observer must then use the word **readout** to stop the exosure. Once the exposure is completed a series of statistics will be displayed as well as the differential photometry. Finally a series of prompts leads the observer through saving the frame to disk and/or tape. Given the recent problems experienced with the tape drive, saving to disk before saving to tape is recomended.
\13 14 transfer	transfer 61x61 pixel "cutouts" centered on the target, check and comparison stars to a separate frame (and **qshow**). This cutout image is useful simply for checking the focus, but by no means necessary.
\hvmaxplot	Check the focus by ploting the image profile
\600 jpexp	Next observation
⋮	
\360 vjflats	Obtain end of run dome_flats if necessary.

Note : A full explanation and description of the above words etc can be found in the documentation *Forth Commands implemented by file jdp*.

B: First supplement to Version 1.1

B.1 Yet More New Words

hvdphot (--), computes the differential magnitude between the target and the stars 2 and 3 specified in the target-word. Individual magnitudes are computed by **hvimag**, and the computed differential magnitudes displayed.

hvimag (*No --), Computes the magitude of star number *No (as defined in the target-word). The magnitude is computed by counting the ADU in the (2halfbox)x(2halfbox) pixel box centered on the brightest pixel within 10 pixels of the Optimum-Star-Positions. Sky subtraction is based on the border pixel annulus. (halfbox and border are variables which can be arbitarily set (eg 15 halfbox !)to suit seeing conditioins on a given night - default values are 10 and 5 respectively). Boxes are displayed to indicate the "counting-box" and "sky-annulus".

hvimaxplot (*No --), plots the row and column of the brightest pixel found by hvimax. This is most useful on a "transfered" frame (see transfer below) since the graph width is only 60 pixels wide, not 384! Note that the column plot shows the target, not star number *No (unless of course *No = 1). hvmaxplot does the plots for the target object. Also, hvimaxplot2 plots the row and column of star number *No but has do make three plots to do so. It. is therefore a little slower.

hvmag (--), computes the magnitude of the Target object. See **hvimag**.

mmag (--), computes the magnitude of the "selected" object. The "counting-box is centered on the brightest pixel within 10 pixels of the current cursor position, which can of course be selected with the mouse, sw, sb, qcur, or acur.

B.2 Observations of GX1+4

In order to obtain meaningful (if low accuracy) online differential photometry at the telescope for the object GX1+4, it is essential that all observers who will be making observations of this object do so in as standard a way as possible. With this in mind the following procedure has been devised for these observations. (The following assumes that the observer is begining with a hard reset. Obviously several of the initial steps can be omitted if

```
obox( s -- ), 11
obox@rc( b r c -- ), 12
oldtclose( -- ), 13
oldtopen( -- ), 13
oldtw( -- ), 13
prc( row col -- ), 12
ra( ra -- ), 13
raaz( ra az -- ), 13
setcaches( -- ), 2
tclose( -- ), 13
topen( -- ), 13
transfer( from to -- ), 13
transferq( from to -- ), 13
tw( -- ), 13
uflats( t -- ), 4
vflats( t -- ), 4
Vjflats( t -- ), 4
xymaxs( row col -- ), 13
yflats( t -- ), 4
```

University of Canterbury Department of Physics & Astronomy

Mt John University Observatory

Mt John Photometrics CCD System

Use and Performance Note Number 15

TH7882 QUANTUM EFFICIENCY

W. Tobin

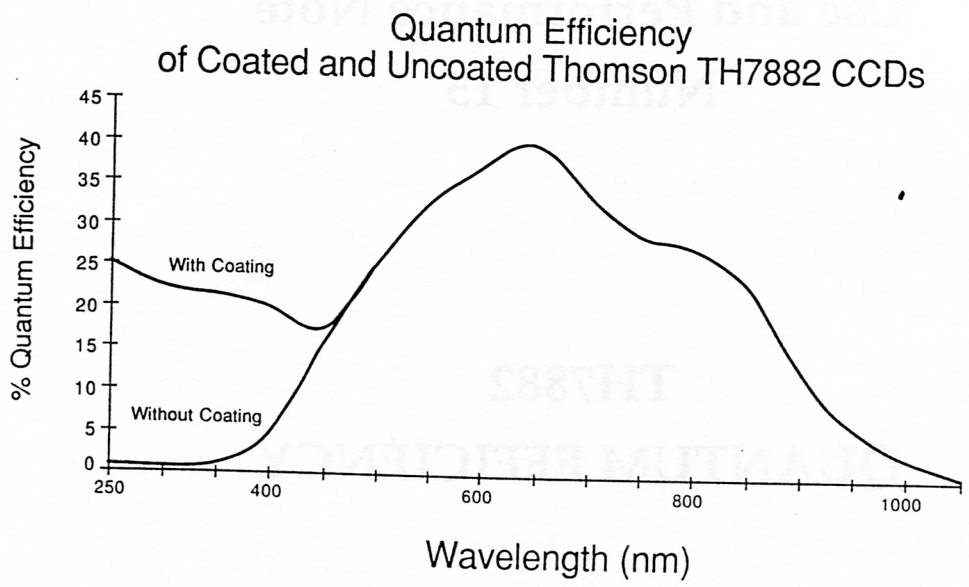
1993 October 12

These Notes are intended for guidance only: individual observers have the sole responsible for the integrity of their own data. Users of the CCD system are encouraged to summarize the performance that they obtain in a Note in this series. Contact Dr. W. Tobin to be allocated a series number.

TH7882 QUANTUM EFFICIENCY

The graph below shows the quantum efficiency of the overcoated TH7882 CDA chip, as claimed by Photomterics. The values are also tabulated at 10nm interval

PHOTOMETRICS LTD.



WL	TH788
300	0.221
310	0.220
320	0.218
330	0.216
340	0.215
350	0.214
360	0.210
370	0.208
380	0.205
390	0.201
400	0.196
410	0.190
420	0.183
430	0.175
440	0.171
450	0.174
460	0.187
470	0.200
480	0.216
490	0.235
500	0.258
510	0.270
520	0.283
530	0.296
540	0.312
550	0.328
560	0.335
570	0.345
580	0.350
590	0.360
600	0.365
610	0.374
620	0.384
630	0.392
640	0.398
650	0.395
660	0.388
670	0.381
680	0.370
690	0.350
700	0.336
710	0.325
720	0.315
730	0.306
740	0.295
750	0.288
760	0.286
770	0.285
780	0.284
790	0.278
800	0.275
810	0.270
820	0.262
830	0.254
840	0.243
850	0.229
860	0.216
870	0.190
880	0.174
890	0.148
900	0.128
910	0.113
920	0.100
930	0.084
940	0.072
950	0.068
960	0.058
970	0.050
980	0.036
990	0.030
1000	0.024
1010	0.022
1020	0.017
1030	0.013
1040	0.009
1050	0.005

University of Canterbury Department of Physics & Astronomy

Mt John University Observatory

Mt John Photometrics CCD System

Use and Performance Note Number 16

ATLAS OF TYPICAL AND ATYPICAL IMAGESS

William Tobin

1993 November 19

These Notes are intended for guidance only: individual observers have the sole responsible for the integrity of their own data. Users of the CCD system are encouraged to summarize the performance that they obtain in a Note in this series. Contact Dr. W. Tobin to be allocated a series number.

ATLAS OF TYPICAL AND ATYPICAL IMAGES

Experience over the past four years has revealed that new users of the Mt John CCD system often fail to recognise abnormalities in the images they are acquiring. This Use & Performance Note presents typical and atypical images so that observers can be forewarned of possible problems. The cause of some of the peculiarities is uncertain.

The images are divided into six groups:

A. Computed images

B. Bias and dark images

C. Imaging photometry

D. Echelle spectroscopy

E. Boller & Chivens intermediate-resolution spectroscopy

F. Miscellaneous images.

Users are advised to scrutinize all the images in this Use & Performance Note, and not just those deriving from the instrument they are using, because many of the problems illustrated may affect all instruments.

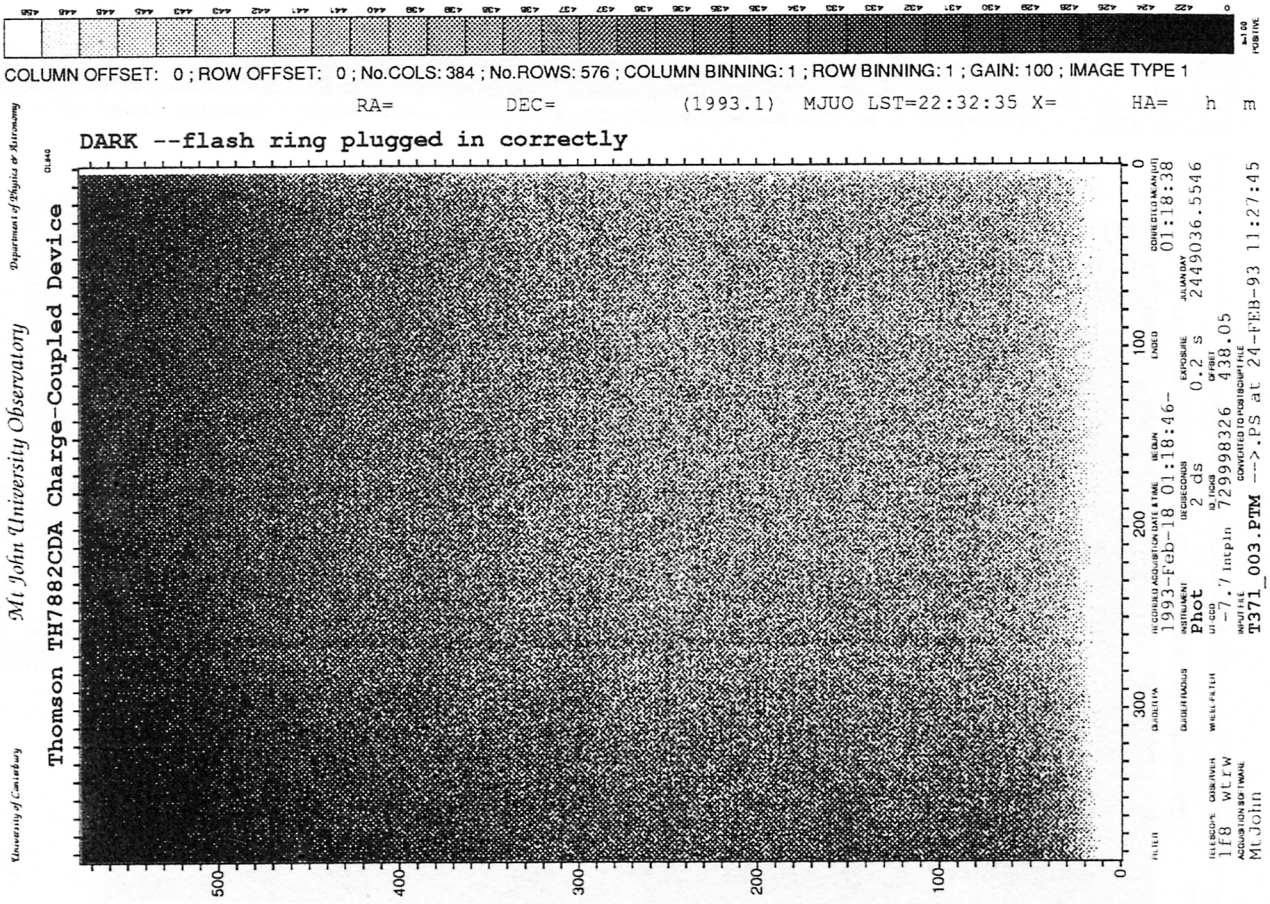
The images in this atlas have mostly been histogram equalized so that a certain fraction of each image is printed at the various greyscale levels. This allows bright and faint features to be seen simultaneously. It can be ascertained whether an image has been printed positive or negative by looking at the legend at the right-hand end of the greyscale bar.

Thanks go to Alan Gilmore, Karen Pollard and others who provided images; and to Jane Preston, who made many of the hardcopies during summer employment 1992-93.

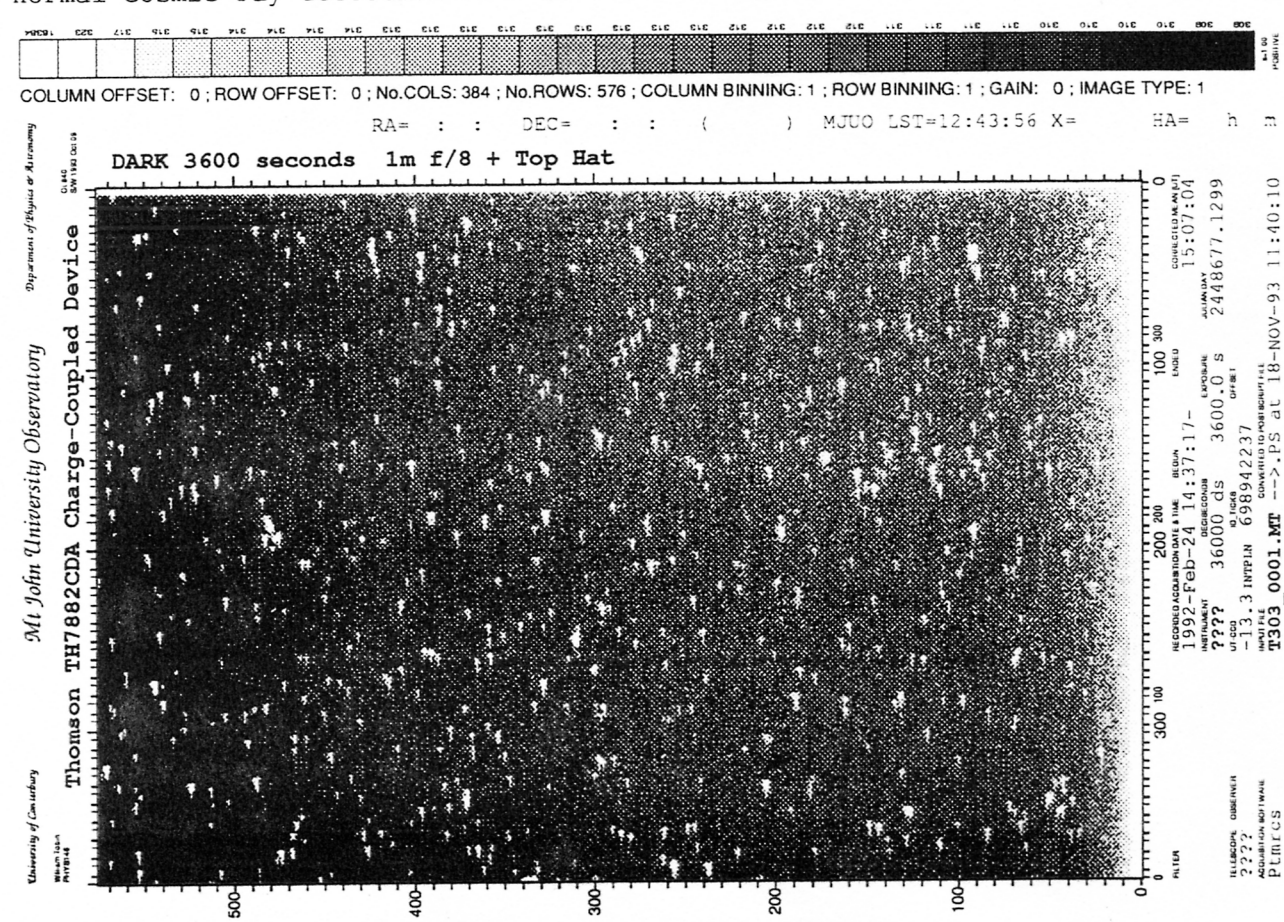
Page 2 missing

Page 3 missing

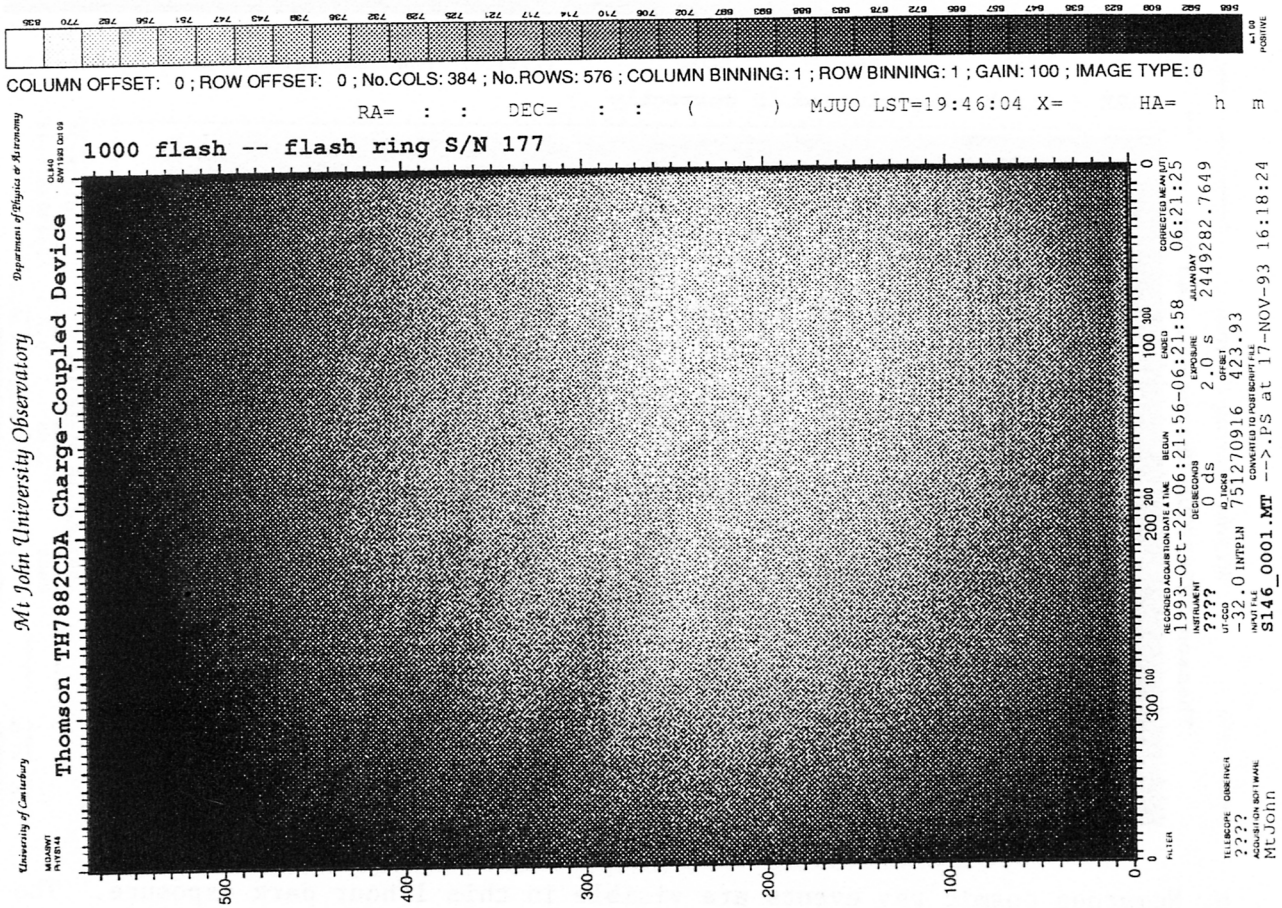
5. A dark frame. The bad rows and columns that originate near the readout point (0,0) have been present since 1989, and possibly since delivery of the system. Their origin is unknown.


COLUMN OFFSET: 0 ; ROW OFFSET: 0 ; No.COLS: 384 ; No.ROWS: 576 ; COLUMN BINNING: 1 ; ROW BINNING: 1 ; GAIN: 100 ; IMAGE TYPE 1
RA= DEC= (1993.1) MJUO LST=22:32:35 X= HA= h m
DARK --flash ring plugged in correctly
Mt John University Observatory
Thomson TH7882CDA Charge-Coupled Device
University of Canterbury
Department of Physics & Astronomy
1993-Feb-18 01:18:46-
Phot
2 ds
0.2 s
2449036.5546
01:18:38
-7.7 IntpIn 729998326 438.05
T371_003.PTM -->.PS at 24-FEB-93 11:27:45
1f8 wtrw
MtJohn

6. Numerous cosmic ray events are visible in this 1 hour dark exposure. The normal cosmic ray detection rate is about 9 events/minute.

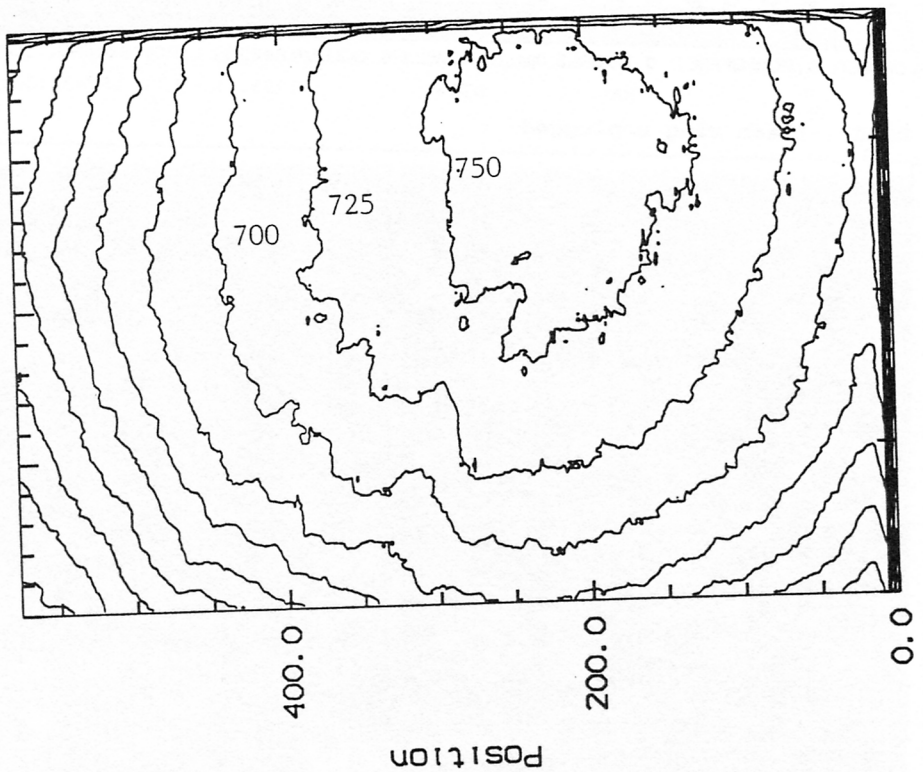

COLUMN OFFSET: 0 ; ROW OFFSET: 0 ; No.COLS: 384 ; No.ROWS: 576 ; COLUMN BINNING: 1 ; ROW BINNING: 1 ; GAIN: 0 ; IMAGE TYPE: 1
RA= : : DEC= : : ( ) MJUO LST=12:43:56 X= HA= h m
DARK 3600 seconds 1m f/8 + Top Hat
Mt John University Observatory
Thomson TH7882CDA Charge-Coupled Device
University of Canterbury
Department of Physics & Astronomy
1992-Feb-24 14:37:17-
????
36000 ds
3600.0 s
2448677.1299
15:07:04
-13.3 IntpIn 698942237
T303_0001.MT -->.PS at 18-NOV-93 11:40:10
????
Pimics

7. The non-uniformity of the (green) flash-ring illumination and sensitivity variations in the TH 7882 CDA chip are easily seen in this image which shows a (bias subtracted) 1000 ms illumination of the flash ring, rather than the usual 70 ms. (See also image 30.)

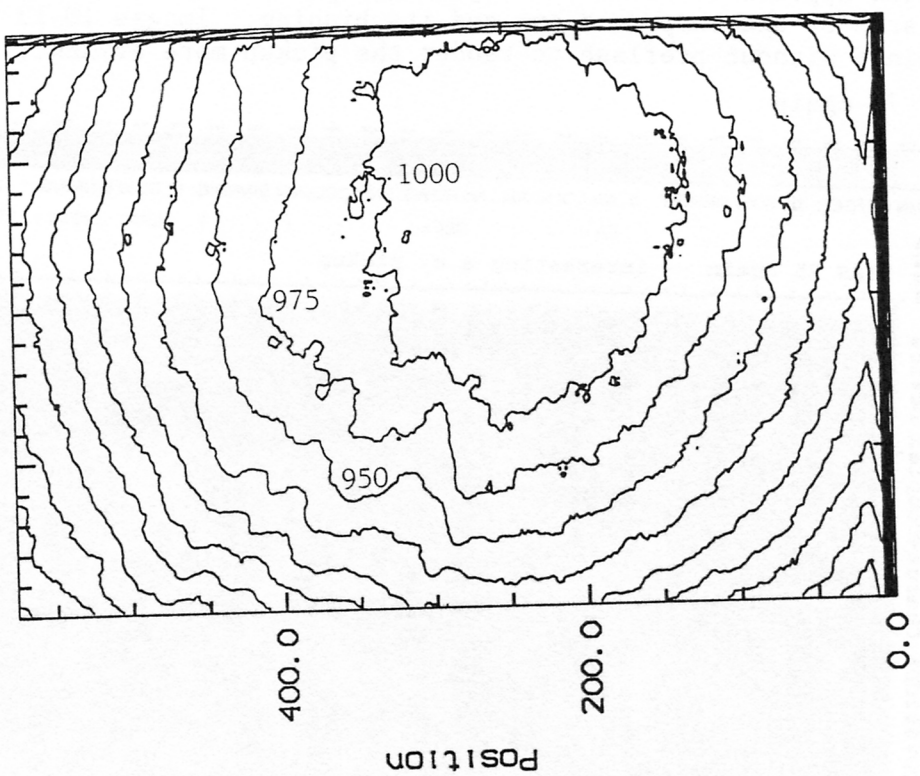

COLUMN OFFSET: 0 ; ROW OFFSET: 0 ; No.COLS: 384 ; No.ROWS: 576 ; COLUMN BINNING: 1 ; ROW BINNING: 1 ; GAIN: 100 ; IMAGE TYPE: 0
RA= : : DEC= : : ( ) MJUO LST=19:46:04 X= HA= h m
1000 flash -- flash ring S/N 177
Mt John University Observatory
Department of Physics & Astronomy
Thomson TH7882CDA Charge-Coupled Device
University of Canterbury
S146_0001.MT -->.PS at 17-NOV-93 16:18:24
MtJohn

8. Contour plots of the flash-ring signals at 100 cgain that are produced in 1000 ms exposures by the two flash-ring/shutter assemblies.

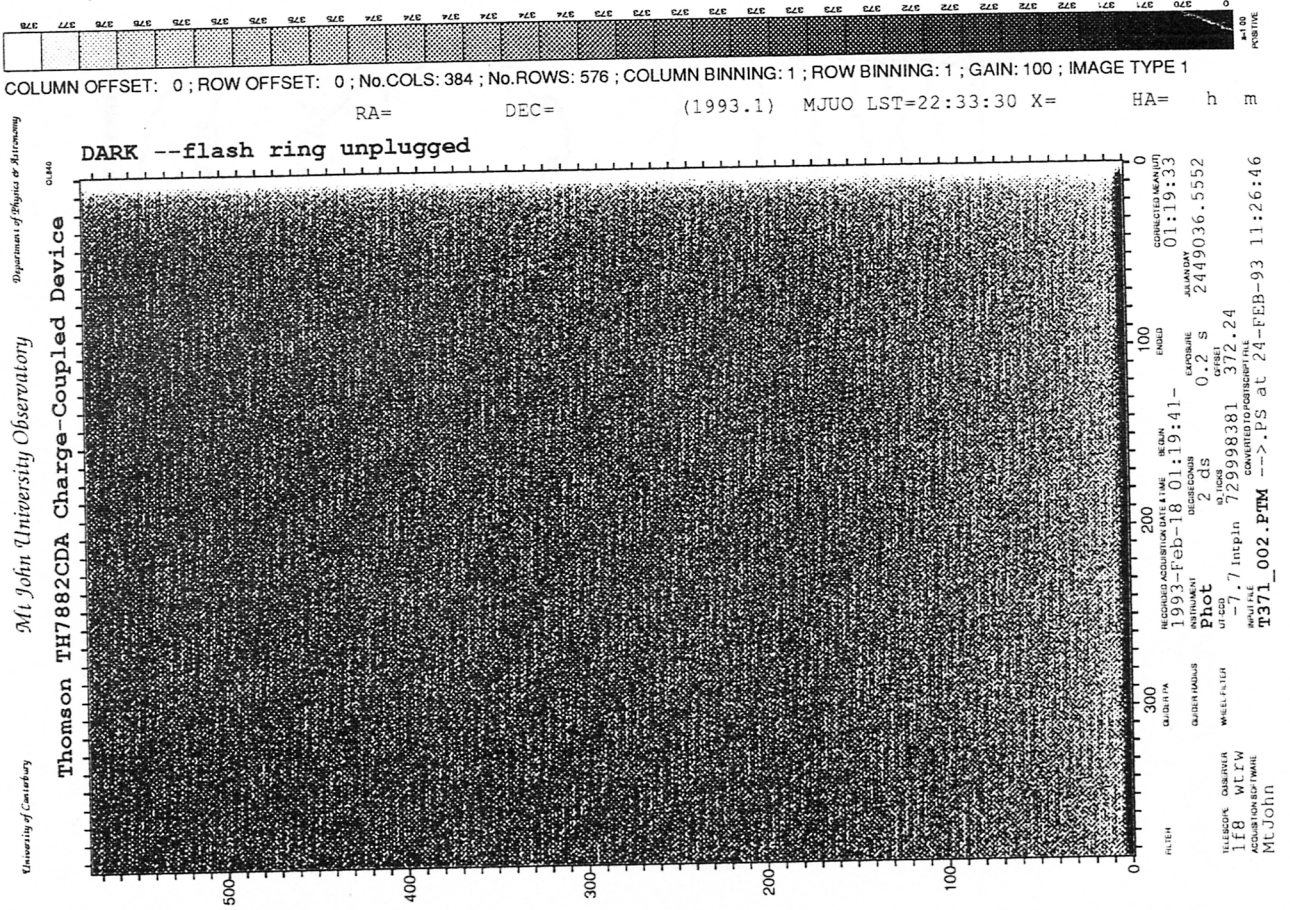
(a) S/N 177



(b) S/N 244

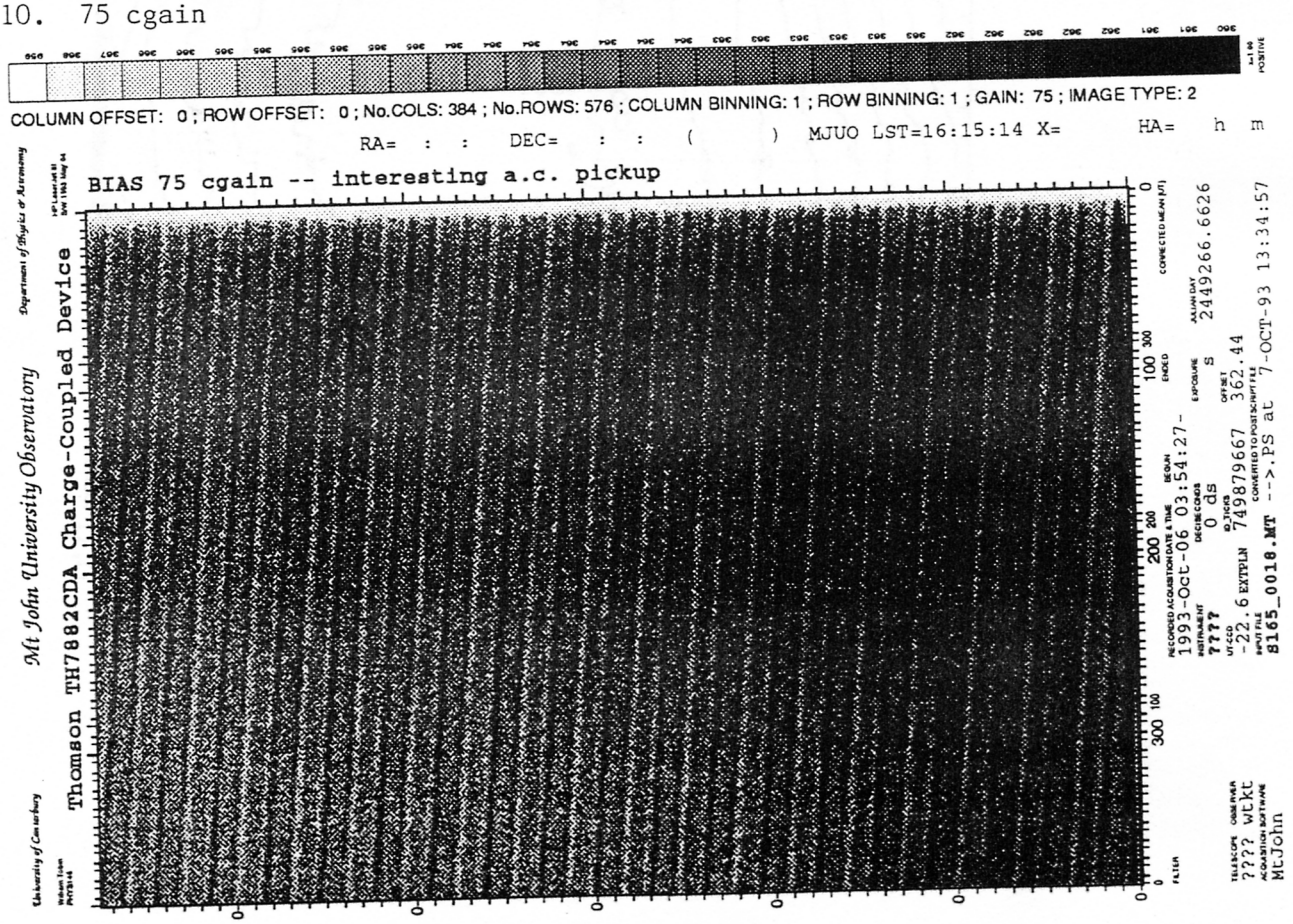


9. The system suffers from a.c. pickup of about 9 electrons peak-to-peak. Without the photon noise associated with the preflash signal, the a.c. pickup is very evident. (100 cgain)

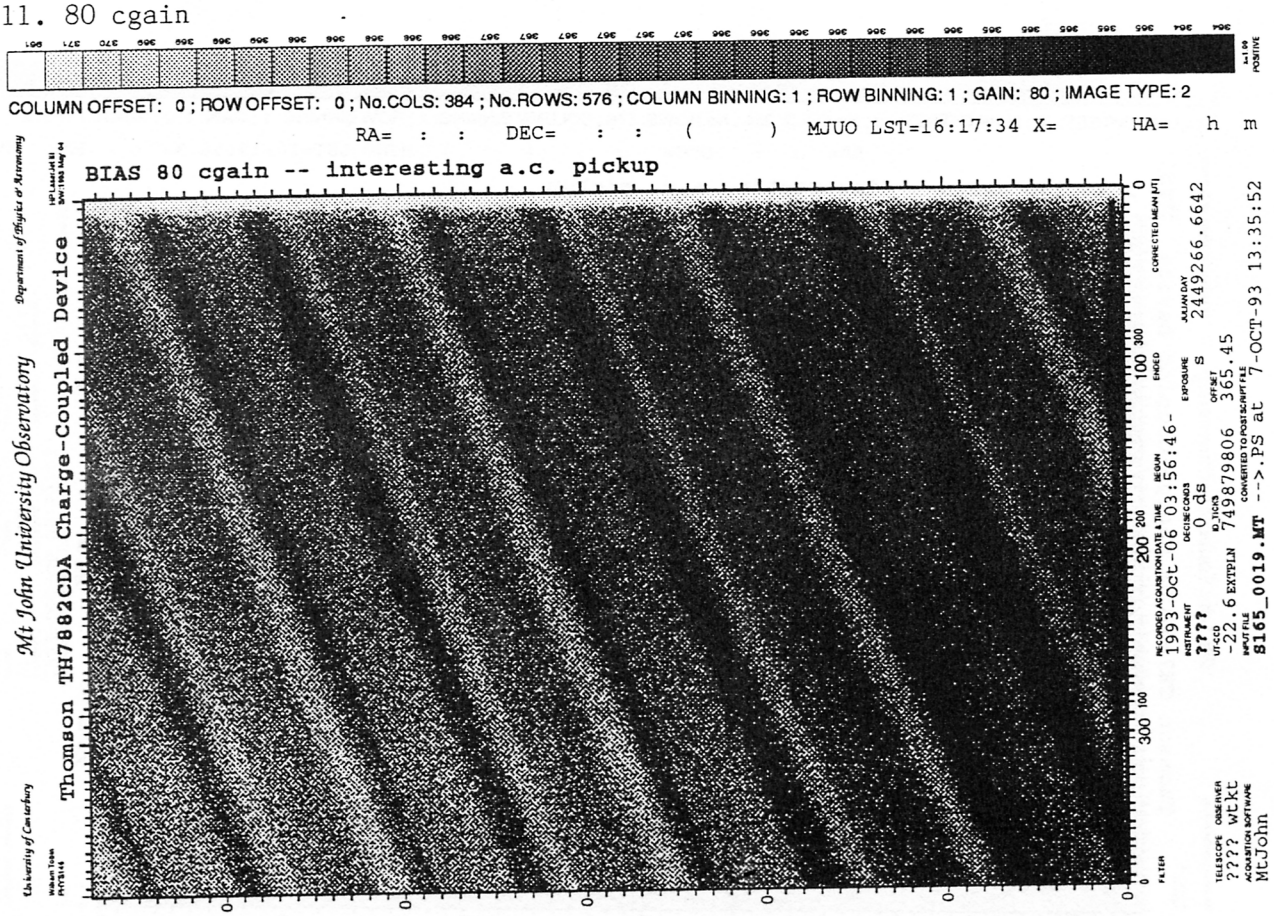

COLUMN OFFSET: 0 ; ROW OFFSET: 0 ; No.COLS: 384 ; No.ROWS: 576 ; COLUMN BINNING: 1 ; ROW BINNING: 1 ; GAIN: 100 ; IMAGE TYPE 1
RA= DEC= (1993.1) MJUO LST=22:33:30 X= HA= h m
DARK --flash ring unplugged
Mt John University Observatory
Thomson TH7882CDA Charge-Coupled Device
University of Canterbury
1993-Feb-18 01:19:41-
Phot
2 ds
0.2 s
2449036.5552
729998381
372.24
T371_002.PTM -->.PS at 24-FEB-93 11:26:46
MtJohn

The appearance of the a.c. pickup depends on the value of cgain used, and the area of the chip read out and its binning. Images 10-13 show examples obtained without preflash to render the pickup more evident.

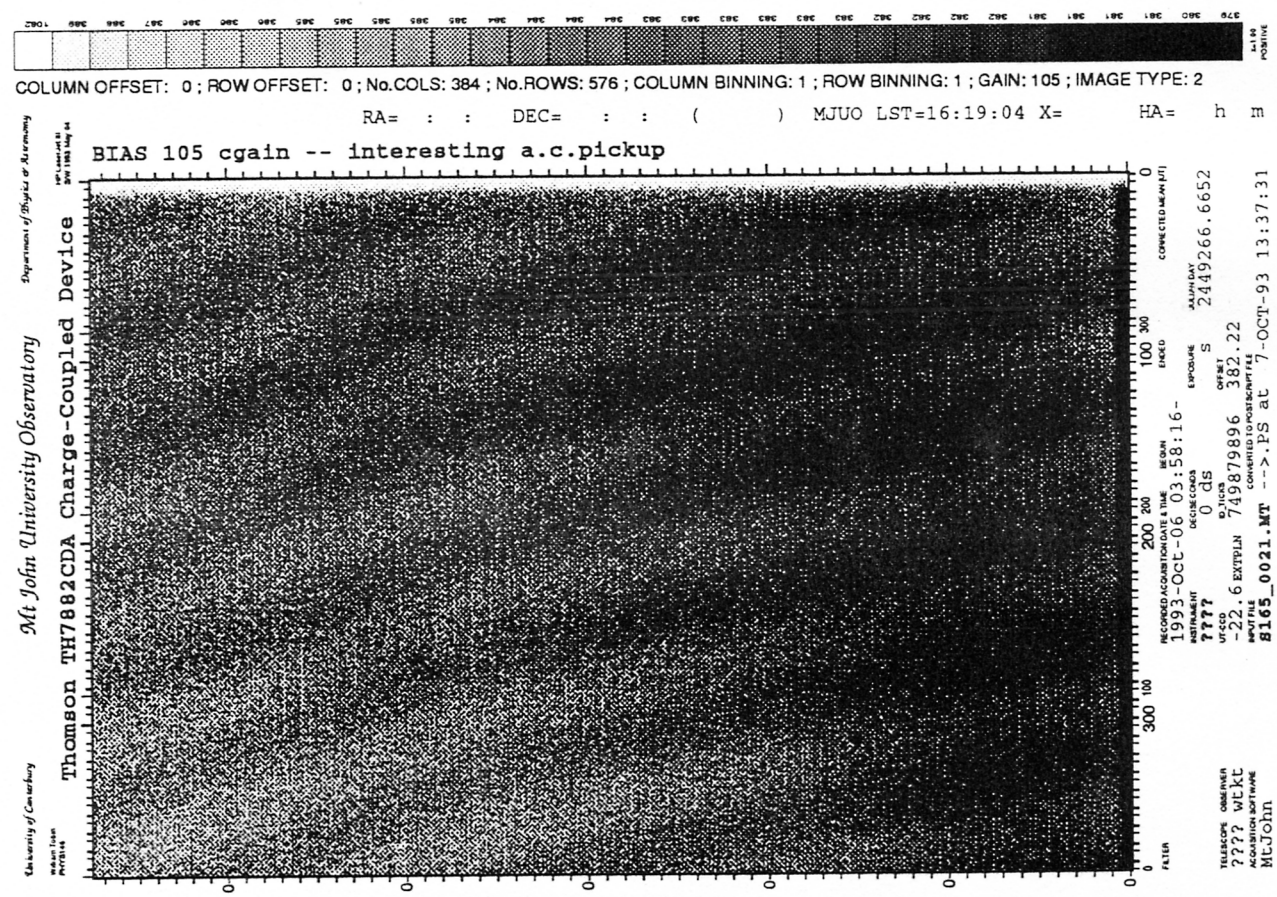
10. 75 cgain


COLUMN OFFSET: 0 ; ROW OFFSET: 0 ; No.COLS: 384 ; No.ROWS: 576 ; COLUMN BINNING: 1 ; ROW BINNING: 1 ; GAIN: 75 ; IMAGE TYPE: 2
RA= : : DEC= : : ( ) MJUO LST=16:15:14 X= HA= h m
BIAS 75 cgain -- interesting a.c. pickup
Mt John University Observatory
Thomson TH7882CDA Charge-Coupled Device
University of Canterbury
1993-Oct-06 03:54:27-
???
0 ds
s
2449266.6626
749879667
362.44
-22.6 EXTPLN
8185_0010.MT -->.PS at 7-OCT-93 13:34:57
????
MtJohn

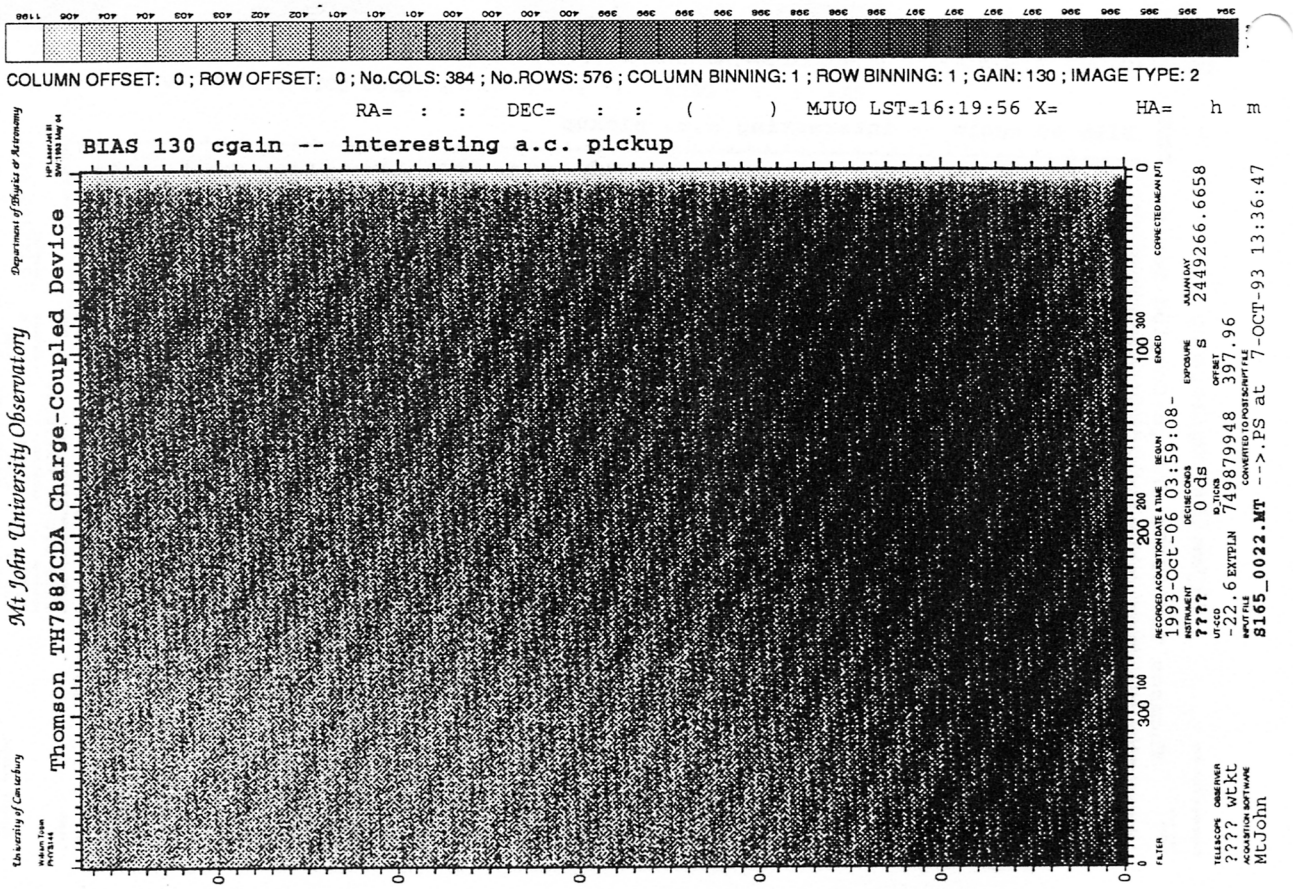
11. 80 cgain


COLUMN OFFSET: 0 ; ROW OFFSET: 0 ; No.COLS: 384 ; No.ROWS: 576 ; COLUMN BINNING: 1 ; ROW BINNING: 1 ; GAIN: 80 ; IMAGE TYPE: 2
RA= : : DEC= : : ( ) MJUO LST=16:17:34 X= HA= h m
BIAS 80 cgain -- interesting a.c. pickup
Mt John University Observatory
Thomson TH7882CDA Charge-Coupled Device
1993-Oct-06 03:56:46-
????
-22.6 EXTPLN
8165_0019.MT -->.PS at 7-OCT-93 13:35:52
MtJohn

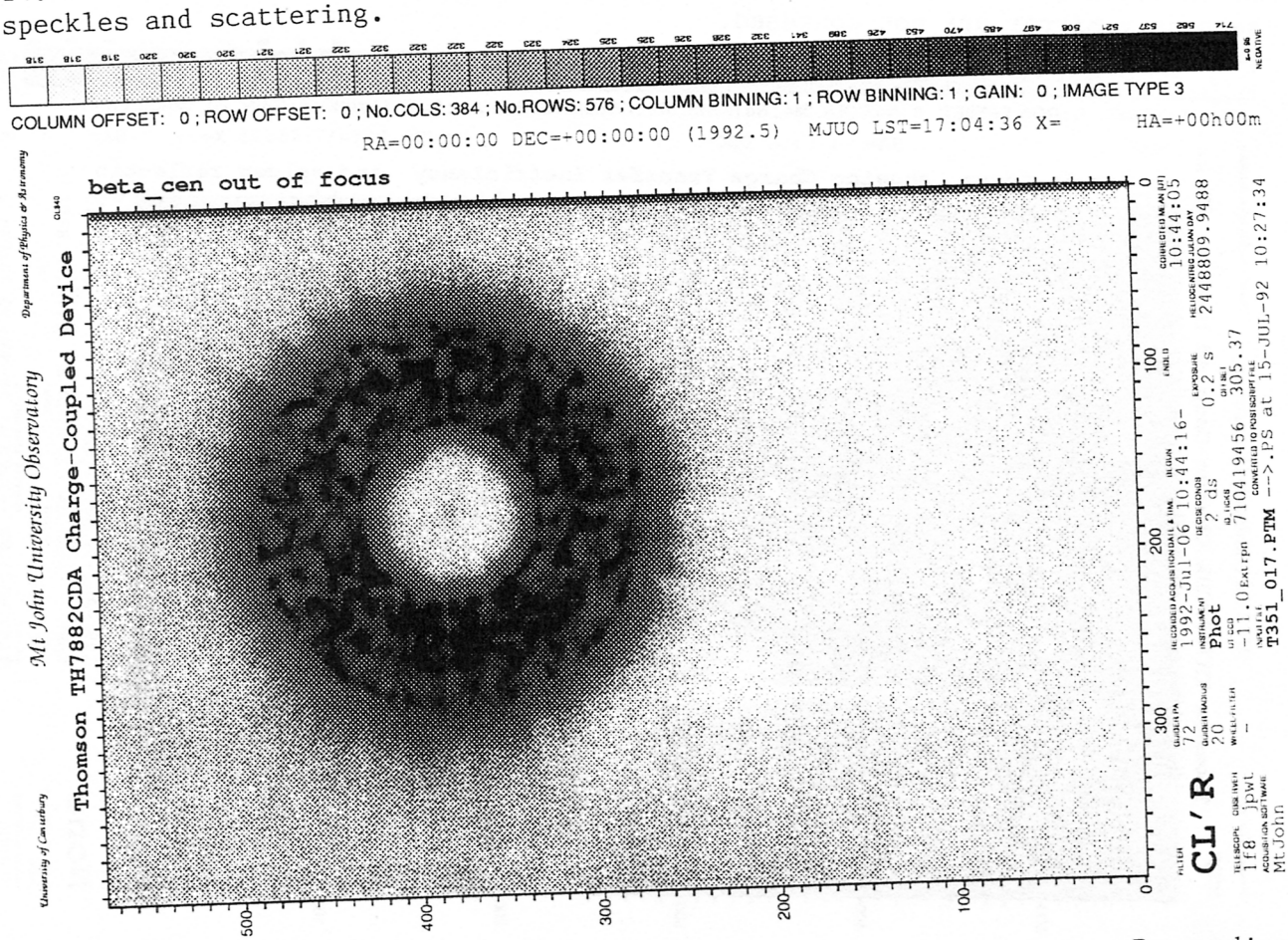
12. 105 cgain


COLUMN OFFSET: 0 ; ROW OFFSET: 0 ; No.COLS: 384 ; No.ROWS: 576 ; COLUMN BINNING: 1 ; ROW BINNING: 1 ; GAIN: 105 ; IMAGE TYPE: 2
RA= : : DEC= : : ( ) MJUO LST=16:19:04 X= HA= h m
BIAS 105 cgain -- interesting a.c.pickup
Mt John University Observatory
Thomson TH7882CDA Charge-Coupled Device
1993-Oct-06 03:58:16-
????
-22.6 EXTPLN
8165_0021.MT -->.PS at 7-OCT-93 13:37:31
MtJohn

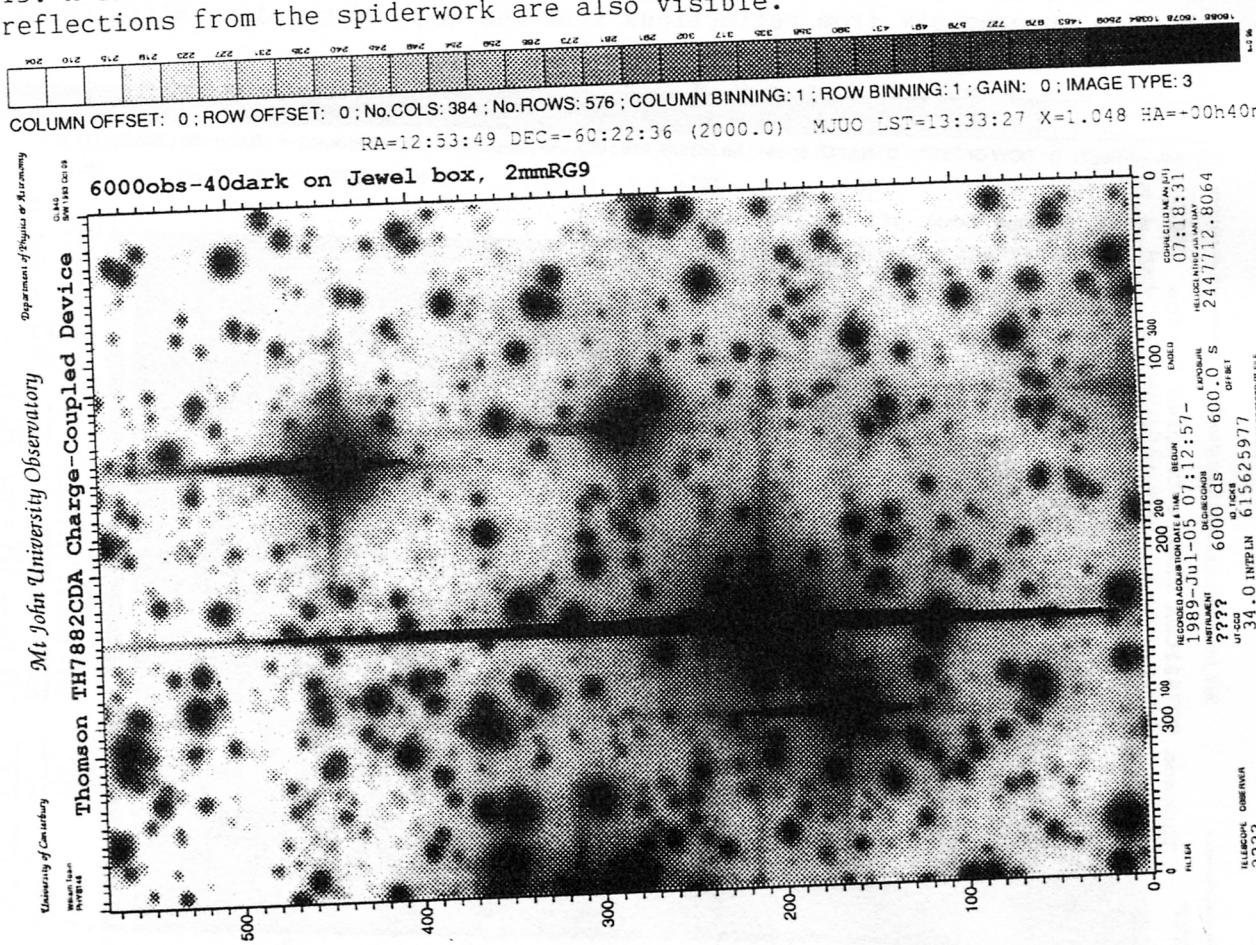
13. 130 cgain


COLUMN OFFSET: 0 ; ROW OFFSET: 0 ; No.COLS: 384 ; No.ROWS: 576 ; COLUMN BINNING: 1 ; ROW BINNING: 1 ; GAIN: 130 ; IMAGE TYPE: 2
RA= : : DEC= : : ( ) MJUO LST=16:19:56 X= HA= h m
BIAS 130 cgain -- interesting a.c. pickup
Mt John University Observatory
Department of Physics & Astronomy
University of Canterbury
Thomson TH7882CDA Charge-Coupled Device
1993-Oct-06 03:59:08-
????
0 ds
-22.6
749879948
397.96
8165_0022.MT
7-OCT-93 13:36:47
????
MtJohn

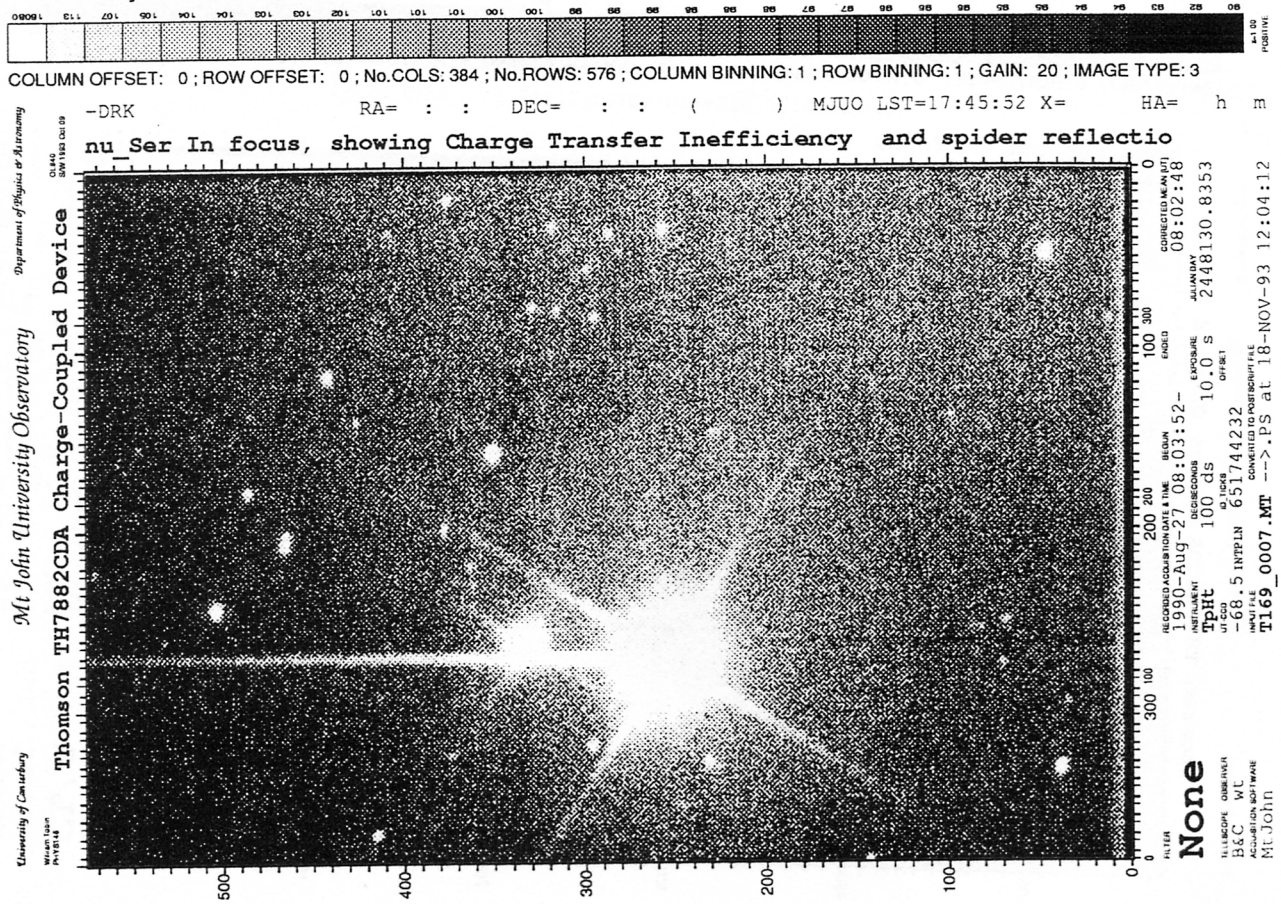
14. An out-of-focus stellar image showing the hollow cone of the telescope beam, speckles and scattering.


COLUMN OFFSET: 0 ; ROW OFFSET: 0 ; No.COLS: 384 ; No.ROWS: 576 ; COLUMN BINNING: 1 ; ROW BINNING: 1 ; GAIN: 0 ; IMAGE TYPE 3
RA=00:00:00 DEC=+00:00:00 (1992.5) MJUO LST=17:04:36 X= HA=+00h00m
beta_cen out of focus
Mt John University Observatory
Thomson TH7882CDA Charge-Coupled Device
CL'R
T351_017.PTM

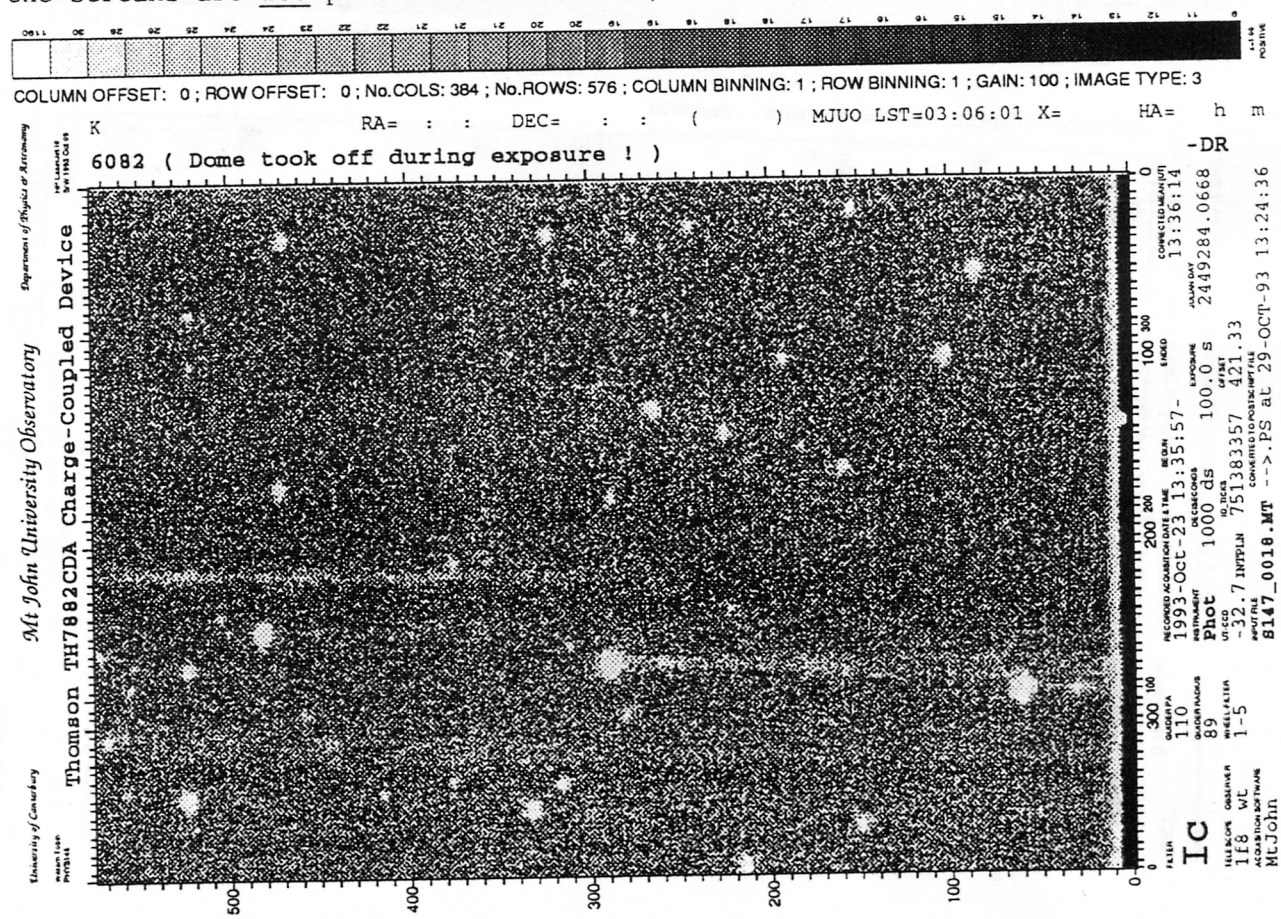
15. A saturated stellar image showing charge overflow down columns. Perpendicular reflections from the spiderwork are also visible.


COLUMN OFFSET: 0 ; ROW OFFSET: 0 ; No.COLS: 384 ; No.ROWS: 576 ; COLUMN BINNING: 1 ; ROW BINNING: 1 ; GAIN: 0 ; IMAGE TYPE: 3
RA=12:53:49 DEC=-60:22:36 (2000.0) MJUO LST=13:33:27 X=1.048 HA=+00h40m
6000obs-40dark on Jewel box, 2mmRG9
Mt John University Observatory
Thomson TH7882CDA Charge-Coupled Device
T013_0025.MT

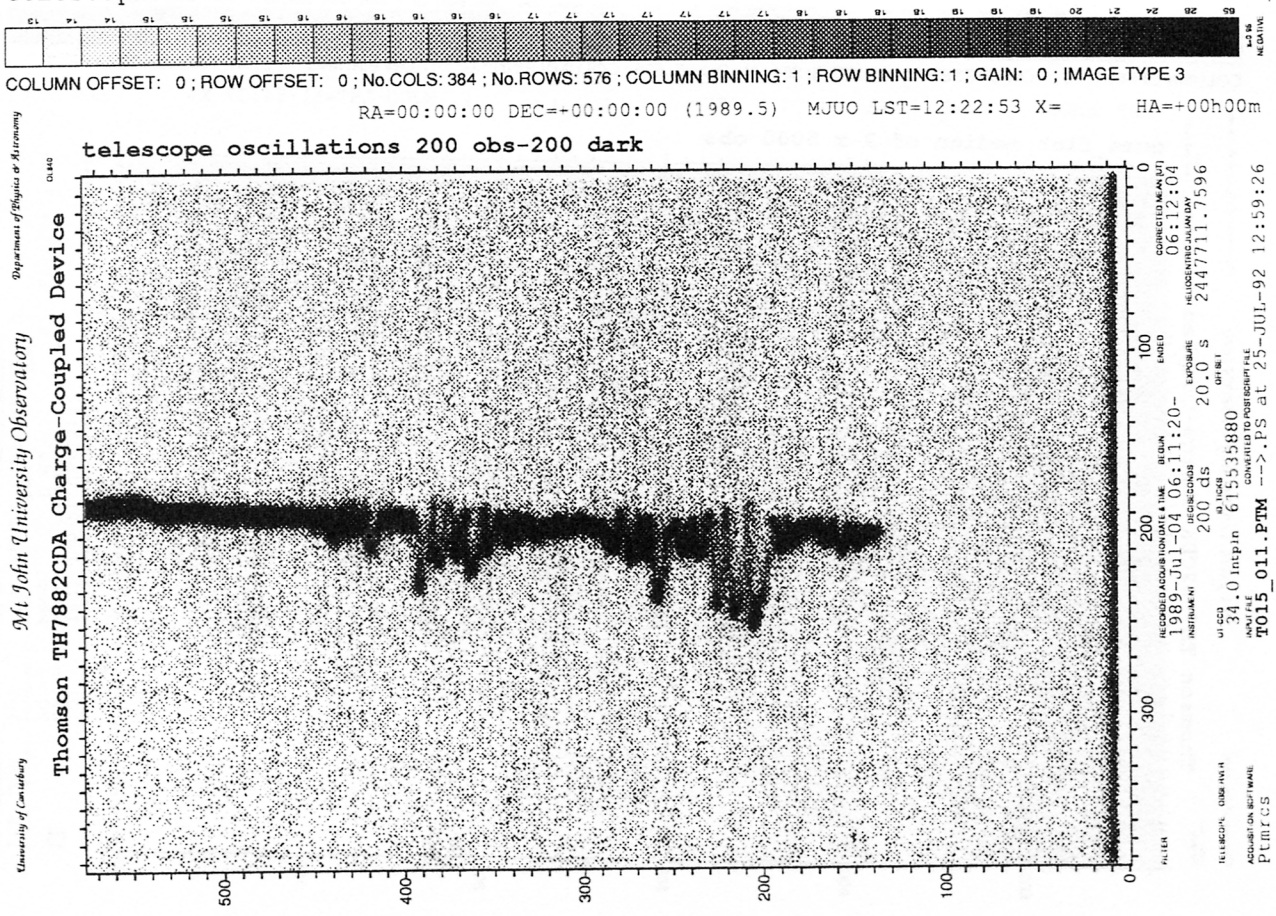
16. A stellar image acquired with the cryostat attached at 30° to its normal orientation so that charge overflow and reflections from the spiderwork of the secondary mirror are not confused.


COLUMN OFFSET: 0 ; ROW OFFSET: 0 ; No.COLS: 384 ; No.ROWS: 576 ; COLUMN BINNING: 1 ; ROW BINNING: 1 ; GAIN: 20 ; IMAGE TYPE: 3
-DRK RA= : : DEC= : : ( ) MJUO LST=17:45:52 X= HA= h m
nu_Ser In focus, showing Charge Transfer Inefficiency and spider reflectio
Mt John University Observatory
Thomson TH7882CDA Charge-Coupled Device
None
T169_0007.MT

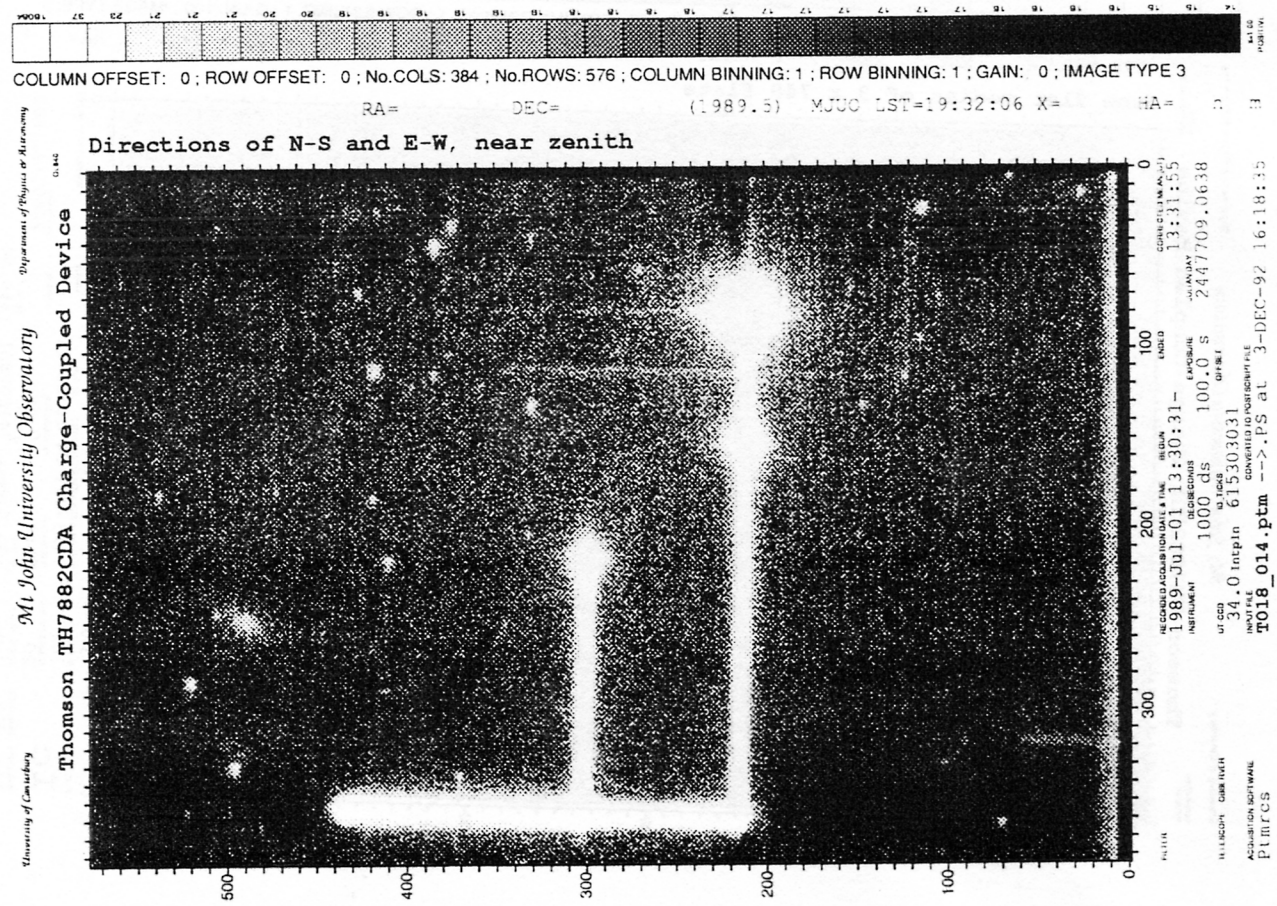
17. The dome started to rotate during this exposure, resulting in image streaking, presumably from reflections from the edge of the dome slit. (Note the streaks are not parallel to columns.)


COLUMN OFFSET: 0 ; ROW OFFSET: 0 ; No.COLS: 384 ; No.ROWS: 576 ; COLUMN BINNING: 1 ; ROW BINNING: 1 ; GAIN: 100 ; IMAGE TYPE: 3
K RA= : : DEC= : : ( ) MJUO LST=03:06:01 X= HA= h m
-DR
6082 (Dome took off during exposure !)
Mt John University Observatory
Thomson TH7882CDA Charge-Coupled Device
Ic
8147_0010.MT

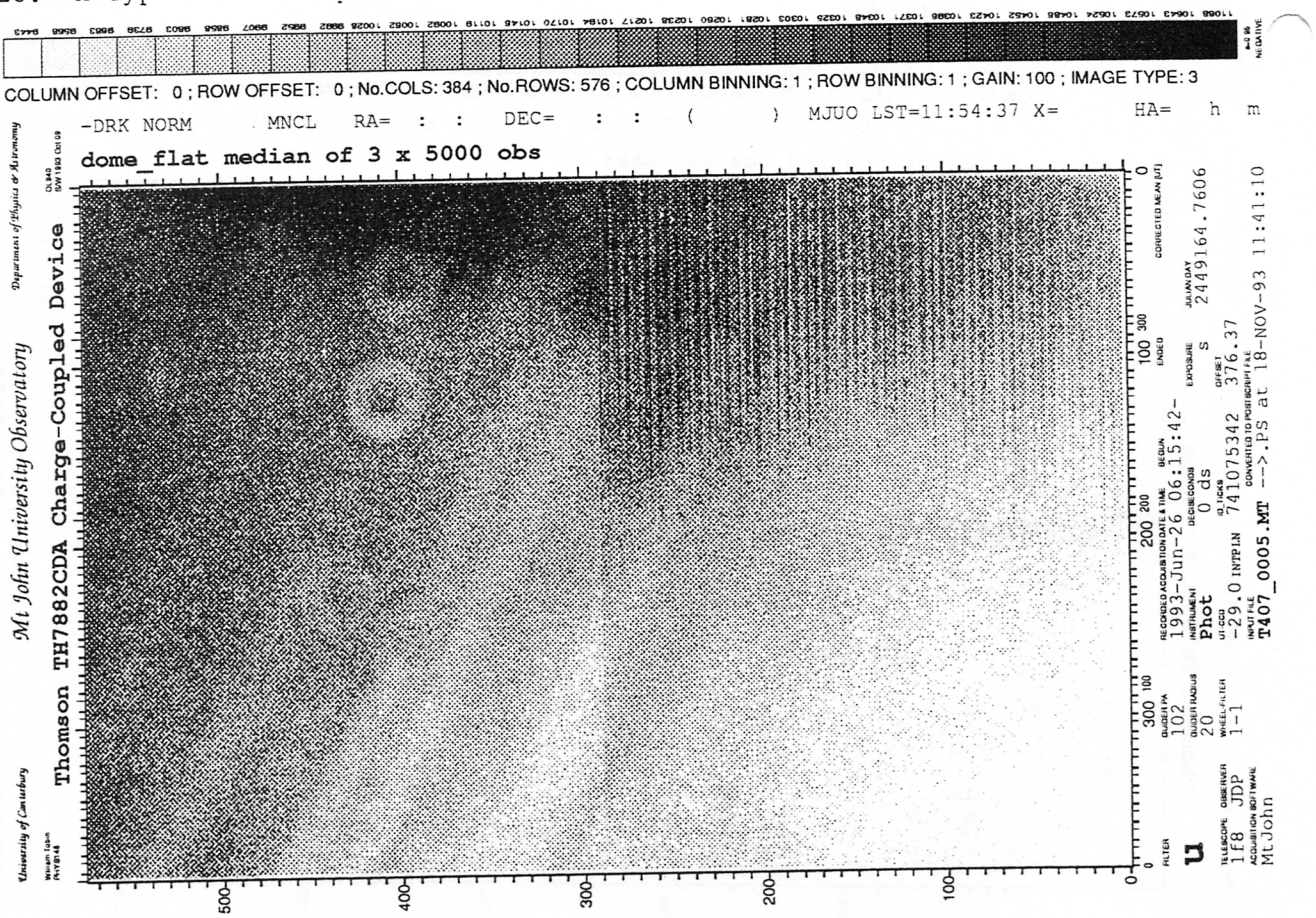
18. A star trail on the 0.6m Boller & Chivens telescope. The drive was turned off to produce the trail, but without the torque motors the wind buffeted the telescope in declination.


COLUMN OFFSET: 0 ; ROW OFFSET: 0 ; No.COLS: 384 ; No.ROWS: 576 ; COLUMN BINNING: 1 ; ROW BINNING: 1 ; GAIN: 0 ; IMAGE TYPE 3
RA=00:00:00 DEC=+00:00:00 (1989.5) MJUO LST=12:22:53 X= HA=+00h00m
telescope oscillations 200 obs-200 dark
Mt John University Observatory
Thomson TH7882CDA Charge-Coupled Device
University of Canterbury
Department of Physics & Astronomy
1989-Jul-04 06:11:20-
200 ds
20.0 s
34.0 Intpln 615535880
T015_011.PTM -->.PS at 25-JUL-92 12:59:26
Ptmrcs
500
400
300
200
100
0

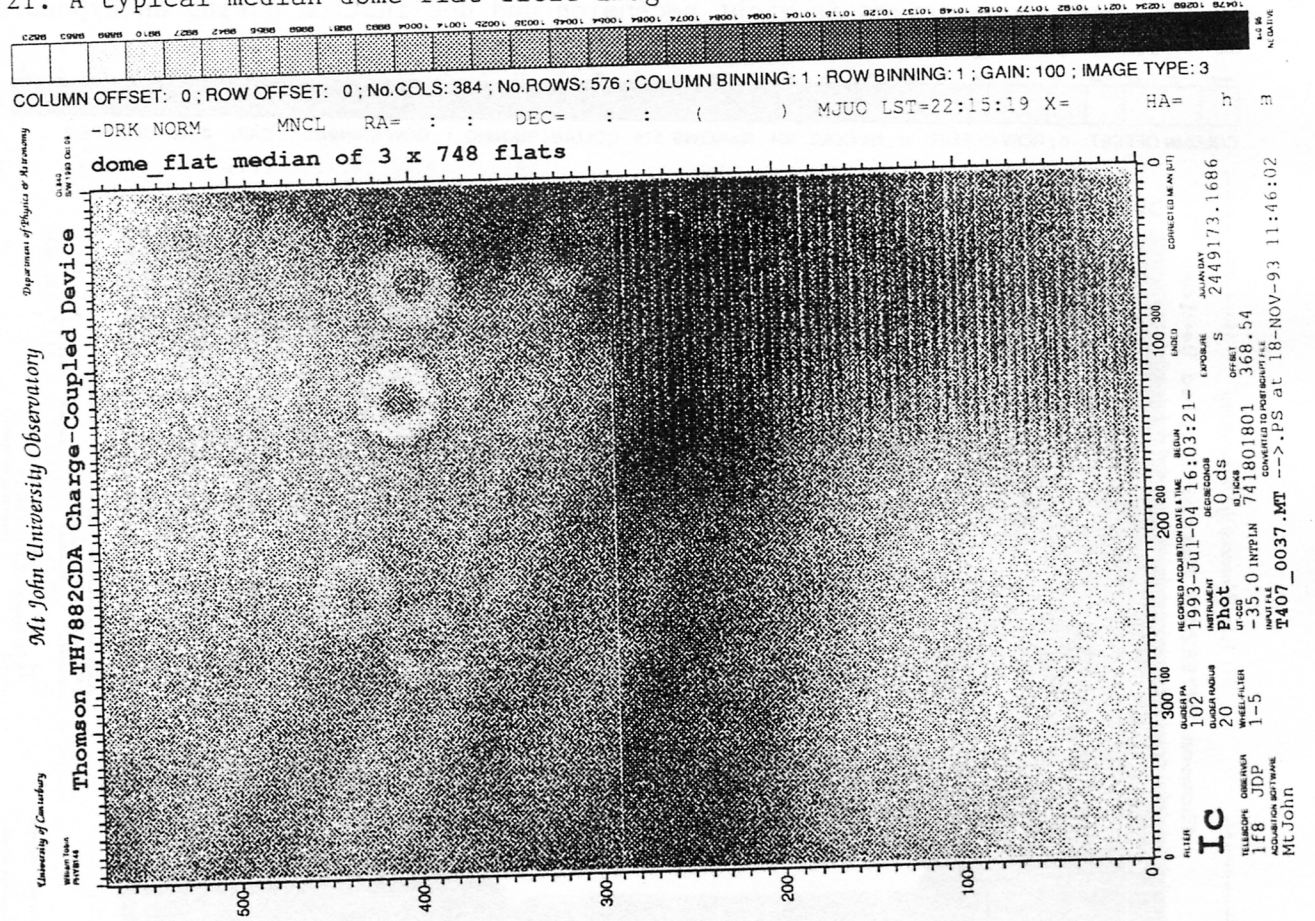
19. The telescope driven in right ascension and declination during an exposure to check the alignment of the chip and polar axis.


COLUMN OFFSET: 0 ; ROW OFFSET: 0 ; No.COLS: 384 ; No.ROWS: 576 ; COLUMN BINNING: 1 ; ROW BINNING: 1 ; GAIN: 0 ; IMAGE TYPE 3
RA= DEC= (1989.5) MJUO LST=19:32:06 X= HA=
Directions of N-S and E-W, near zenith
Mt John University Observatory
Thomson TH7882CDA Charge-Coupled Device
University of Canterbury
Department of Physics & Astronomy
1989-Jul-01 13:30:31-
1000 ds
100.0 s
34.0 Intpln 615303031
T018_014.ptm -->.PS at 3-DEC-92 16:18:35
Ptmrcs
500
400
300
200
100
0

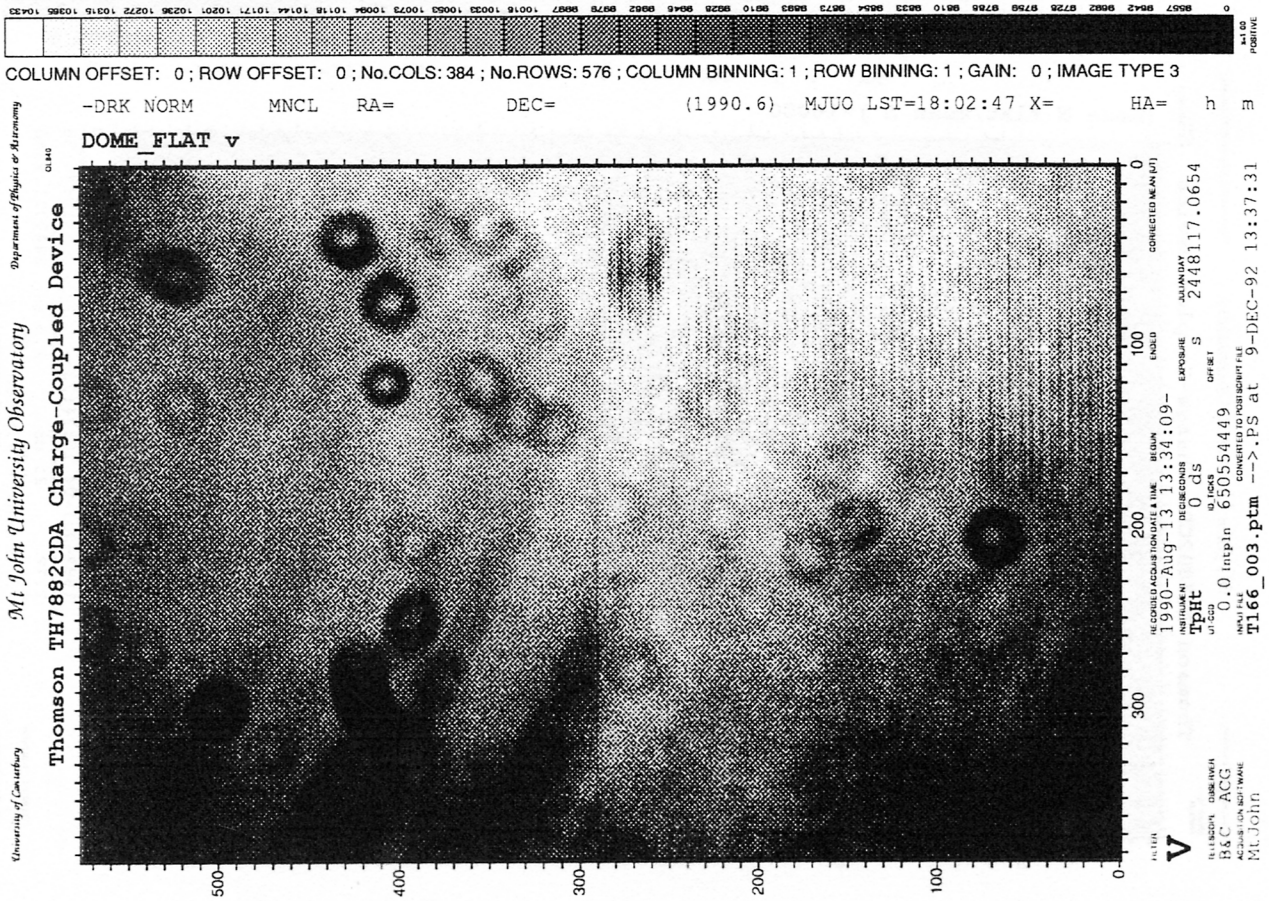
20. A typical median dome flat-field image in Strömgren u.


COLUMN OFFSET: 0 ; ROW OFFSET: 0 ; No.COLS: 384 ; No.ROWS: 576 ; COLUMN BINNING: 1 ; ROW BINNING: 1 ; GAIN: 100 ; IMAGE TYPE: 3
-DRK NORM MNCL RA= : : DEC= : : ( ) MJUO LST=11:54:37 X= HA=
dome_flat median of 3 x 5000 obs
Mt John University Observatory
Thomson TH7882CDA Charge-Coupled Device
University of Canterbury
Department of Physics & Astronomy
FILTER u
1993-Jun-26 06:15:42-
Phot
2449164.7606
T407_0005.MT

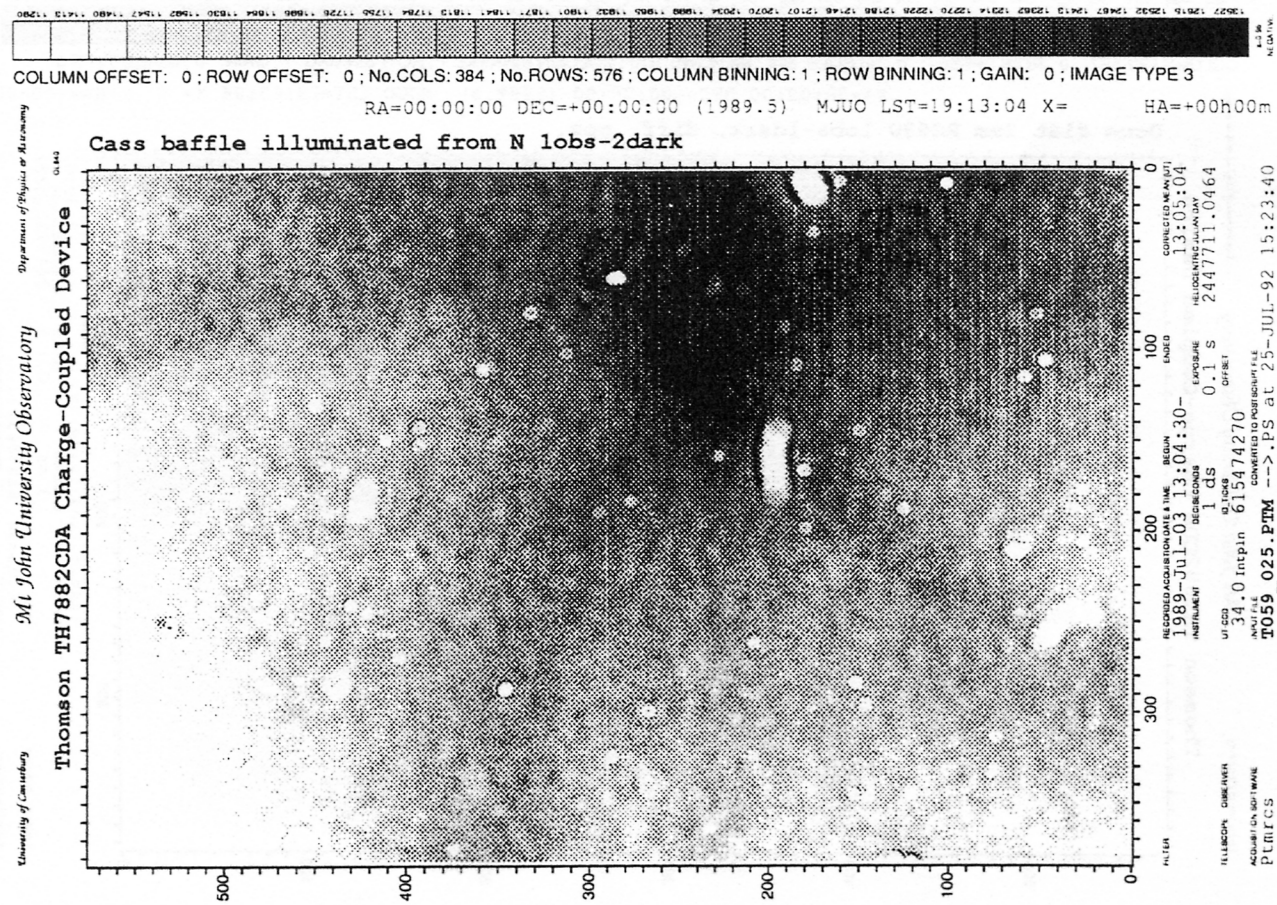
21. A typical median dome flat-field image in Cousins I.


COLUMN OFFSET: 0 ; ROW OFFSET: 0 ; No.COLS: 384 ; No.ROWS: 576 ; COLUMN BINNING: 1 ; ROW BINNING: 1 ; GAIN: 100 ; IMAGE TYPE: 3
-DRK NORM MNCL RA= : : DEC= : : ( ) MJUO LST=22:15:19 X= HA=
dome_flat median of 3 x 748 flats
Mt John University Observatory
Thomson TH7882CDA Charge-Coupled Device
University of Canterbury
Department of Physics & Astronomy
FILTER Ic
1993-Jul-04 16:03:21-
Phot
2449173.1686
T407_0037.MT

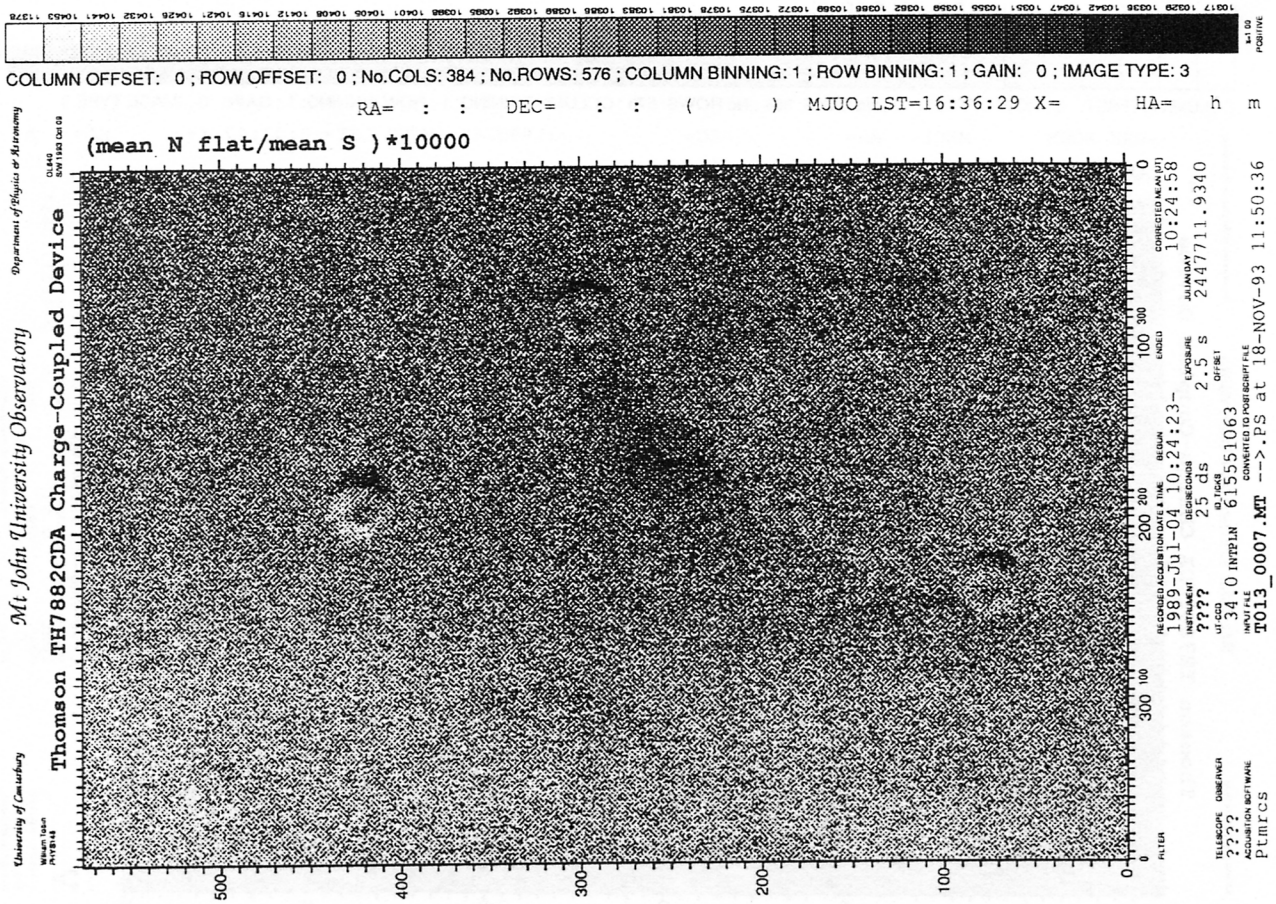
22. A flat-field image showing annular shadows cast by dust specks on the cryostat quartz entrance window. Because of telescope flexure these dust rings do not flatfield away satisfactorily. It is time to ask the Superintendent to clean the quartz window!


COLUMN OFFSET: 0 ; ROW OFFSET: 0 ; No.COLS: 384 ; No.ROWS: 576 ; COLUMN BINNING: 1 ; ROW BINNING: 1 ; GAIN: 0 ; IMAGE TYPE 3
-DRK NORM MNCL RA= DEC= (1990.6) MJUO LST=18:02:47 X= HA= h m
DOME_FLAT v
Mt John University Observatory
Thomson TH7882CDA Charge-Coupled Device
University of Canterbury
Department of Physics & Astronomy
FILTER V
TELESCOPE OBSERVER B&C ACG
ACQUISITION SOFTWARE MtJohn
RECORDED ACQUISITION DATE & TIME BEGIN 1990-Aug-13 13:34:09-
INSTRUMENT TpHt
UT GOO 0.0 Intpln
DECIDEGREES 0 ds
GLTICKS 650554449
EXPOSURE s
OFFSET
ENDED
CONNECTED MEAN (UT)
JULIAN DAY 2448117.0654
INPUT FILE T166_003.ptm
CONVERTED TO POSTSCRIPT FILE -->.PS at 9-DEC-92 13:37:31

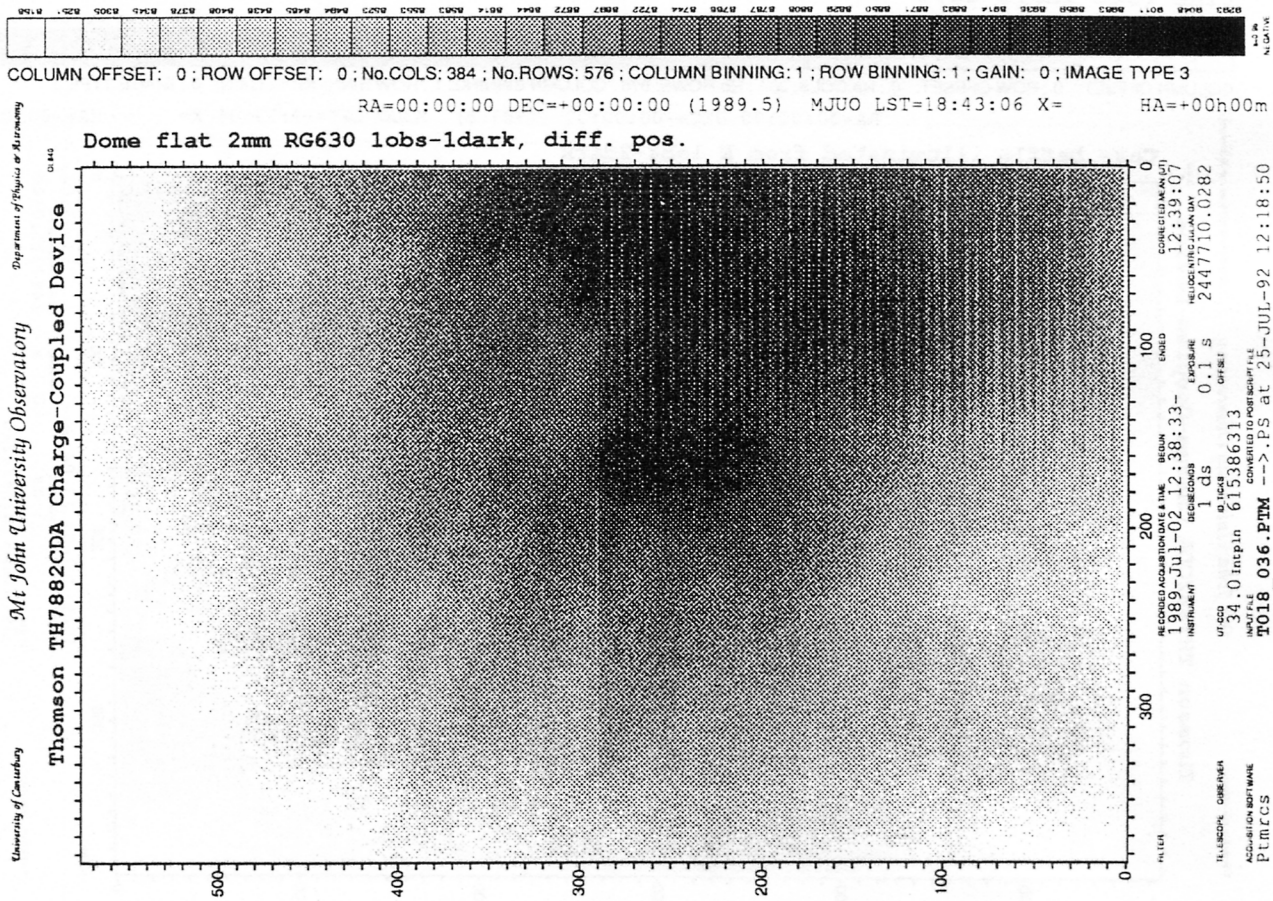
23. Light shone into the primary chimney baffle reveals many other irregularities and dust specks. Note also the shutter petals consequent on the short exposure time (see image 26).


COLUMN OFFSET: 0 ; ROW OFFSET: 0 ; No.COLS: 384 ; No.ROWS: 576 ; COLUMN BINNING: 1 ; ROW BINNING: 1 ; GAIN: 0 ; IMAGE TYPE 3
RA=00:00:00 DEC=+00:00:00 (1989.5) MJUO LST=19:13:04 X= HA=+00h00m
Cass baffle illuminated from N 1obs-2dark
Mt John University Observatory
Thomson TH7882CDA Charge-Coupled Device
University of Canterbury
Department of Physics & Astronomy
FILTER
TELESCOPE OBSERVER
ACQUISITION SOFTWARE PlotPCS
RECORDED ACQUISITION DATE & TIME BEGIN 1989-Jul-03 13:04:30-
INSTRUMENT
UT GOO 34.0 Intpln
DECIDEGREES 1 ds
GLTICKS 615474270
EXPOSURE 0.1 s
OFFSET
ENDED
CONNECTED MEAN (UT) 13:05:04
HELIOCENTRIC JULIAN DAY 2447711.0464
INPUT FILE T059_025.PTM
CONVERTED TO POSTSCRIPT FILE -->.PS at 25-JUL-92 15:23:40

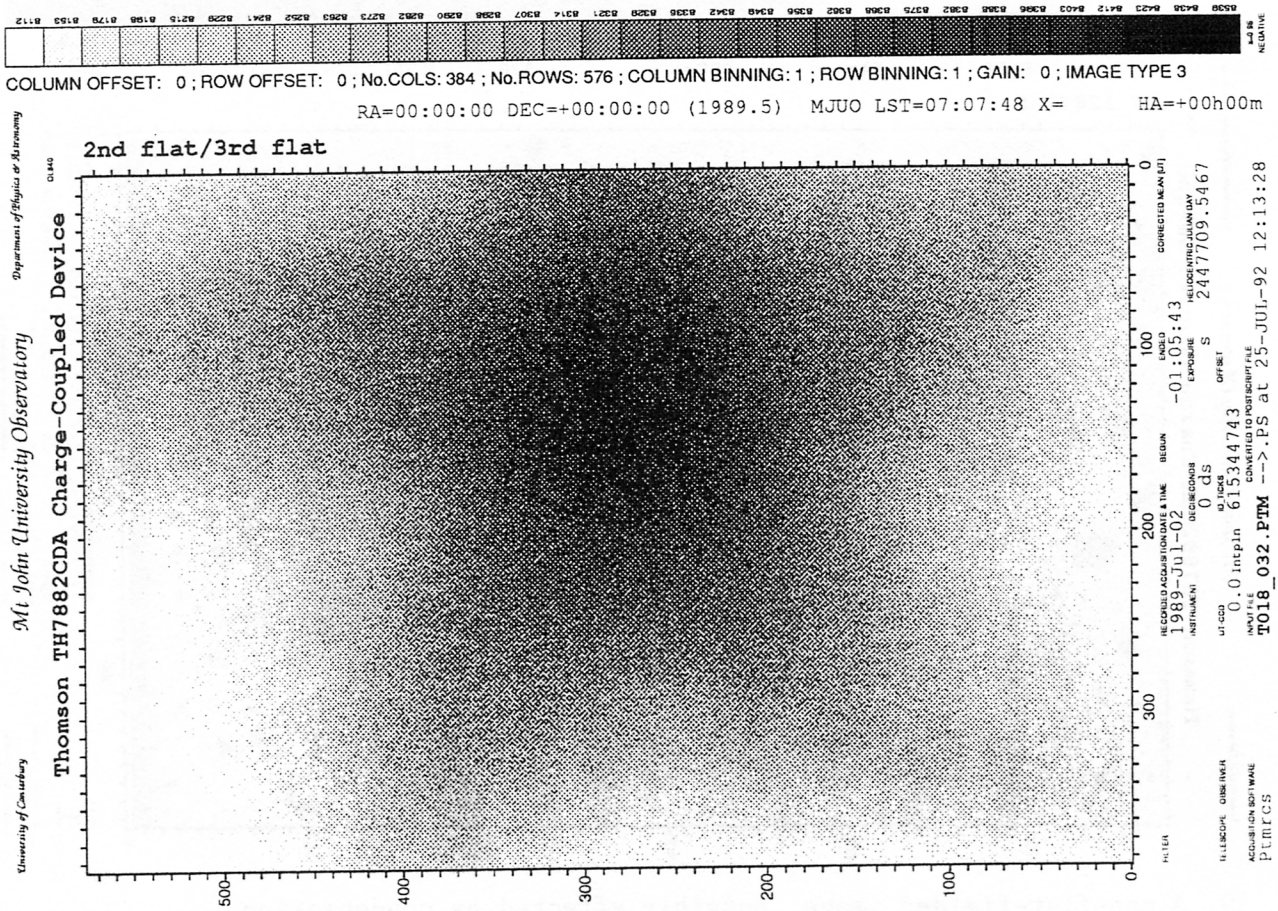
24. A ratio of two flat fields taken at different telescope positions shows that dust rings do not correct well.


COLUMN OFFSET: 0 ; ROW OFFSET: 0 ; No.COLS: 384 ; No.ROWS: 576 ; COLUMN BINNING: 1 ; ROW BINNING: 1 ; GAIN: 0 ; IMAGE TYPE: 3
RA= : : DEC= : : ( ) MJUO LST=16:36:29 X= HA= h m
(mean N flat/mean S)*10000
Mt John University Observatory
Thomson TH7882CDA Charge-Coupled Device
University of Canterbury
T013_0007.MT -->.PS at 18-NOV-93 11:50:36
Ptmrcs

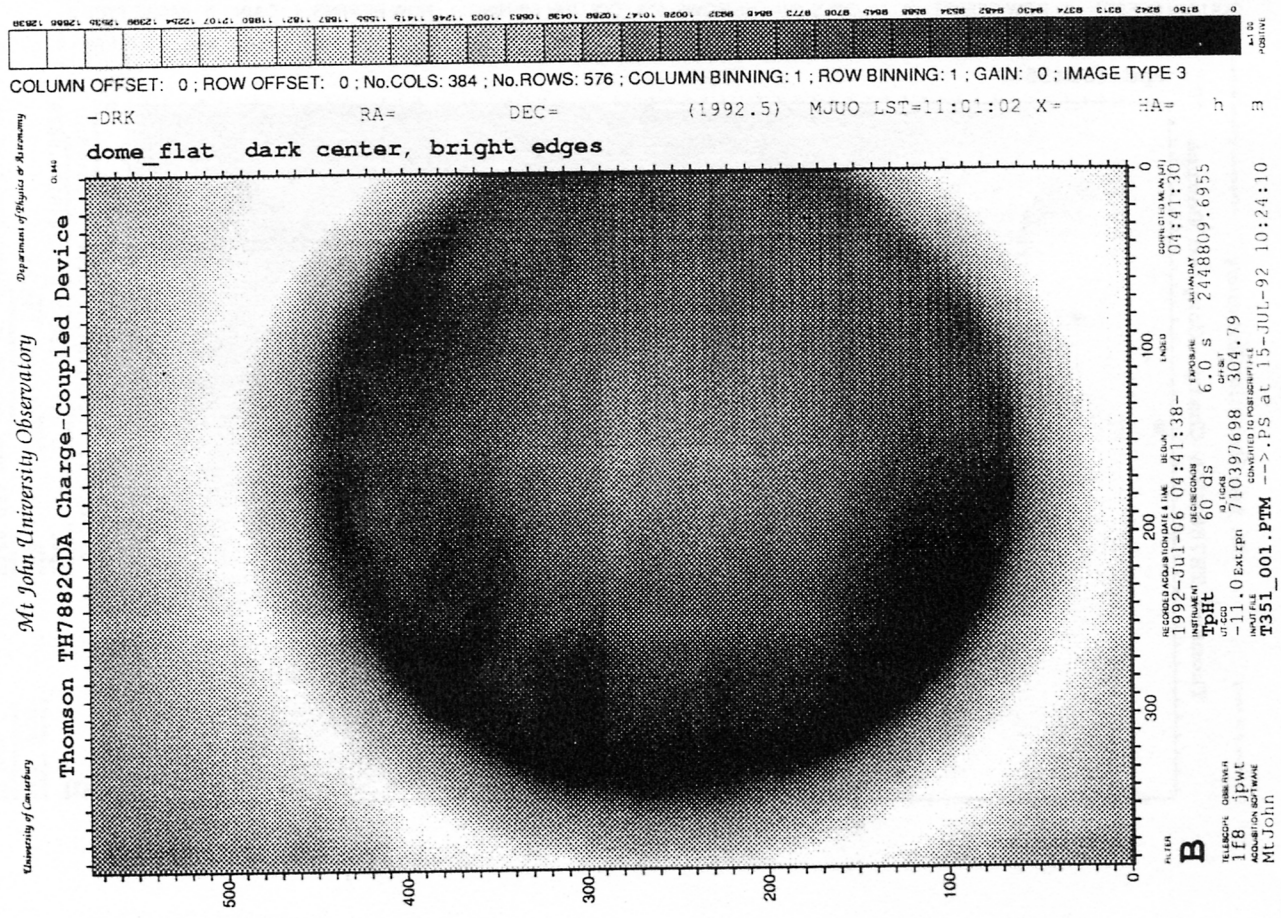
25. The telescope beam can be seen in this dome flat field taken when the telescope was <u>not</u> focused on infinity. <u>Focus the telescope before obtaining flat fields.</u>


COLUMN OFFSET: 0 ; ROW OFFSET: 0 ; No.COLS: 384 ; No.ROWS: 576 ; COLUMN BINNING: 1 ; ROW BINNING: 1 ; GAIN: 0 ; IMAGE TYPE 3
RA=00:00:00 DEC=+00:00:00 (1989.5) MJUO LST=18:43:06 X= HA=+00h00m
Dome flat 2mm RG630 1obs-1dark, diff. pos.
Mt John University Observatory
Thomson TH7882CDA Charge-Coupled Device
University of Canterbury
T018_036.PTM -->.PS at 25-JUL-92 12:18:50
Ptmrcs

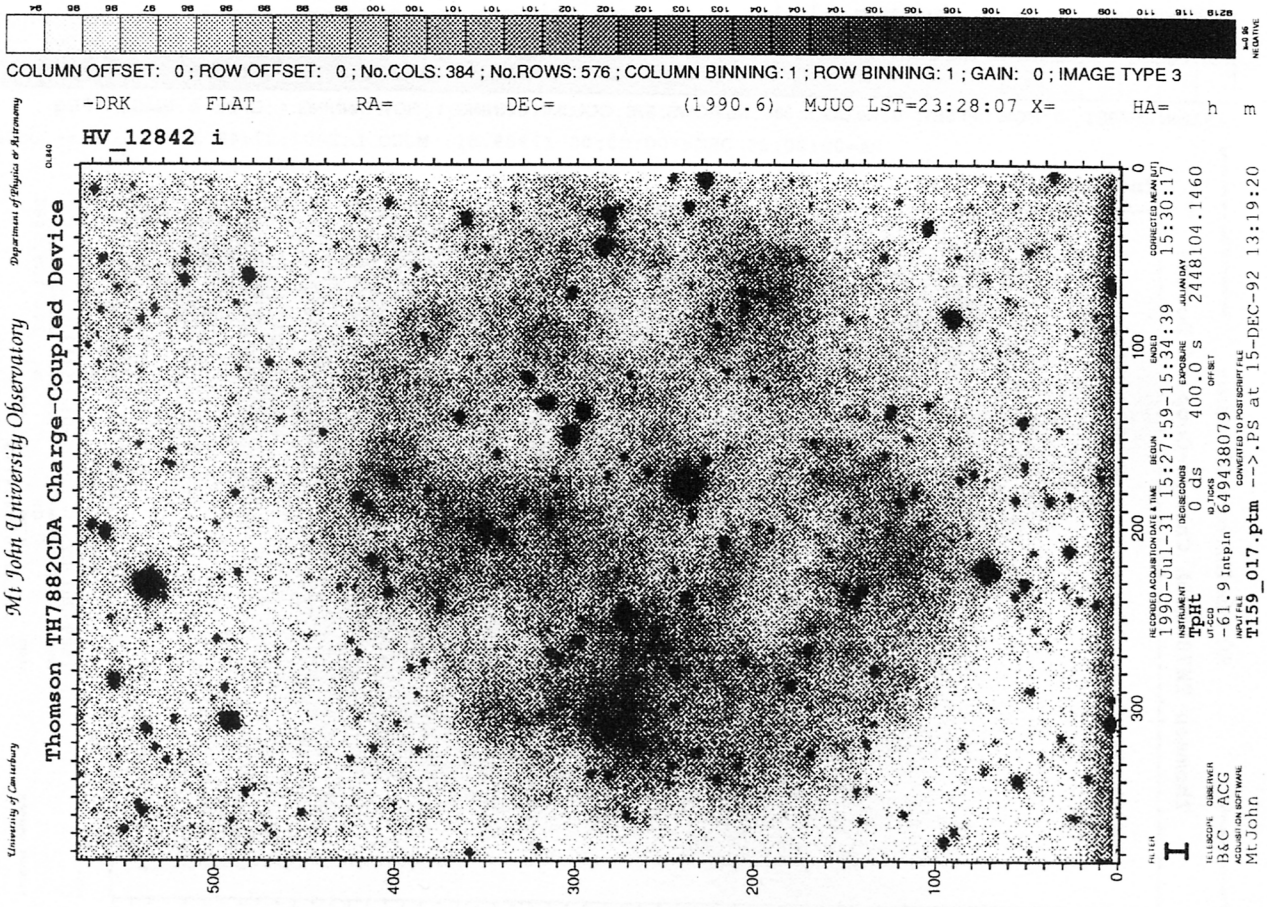
26. The ratio of a very short to a long exposure flat field shows the 5-petalled structure of the shutter blades. Do not use exposure times which are too short!


COLUMN OFFSET: 0 ; ROW OFFSET: 0 ; No.COLS: 384 ; No.ROWS: 576 ; COLUMN BINNING: 1 ; ROW BINNING: 1 ; GAIN: 0 ; IMAGE TYPE 3
RA=00:00:00 DEC=+00:00:00 (1989.5) MJUO LST=07:07:48 X= HA=+00h00m
2nd flat/3rd flat
Mt John University Observatory
Thomson TH7882CDA Charge-Coupled Device
University of Canterbury
Department of Physics & Astronomy
1989-Jul-02
-01:05:43
0 ds
2447709.5467
615344743
T018_032.PTM -->.PS at 25-JUL-92 12:13:28
Pimrcs

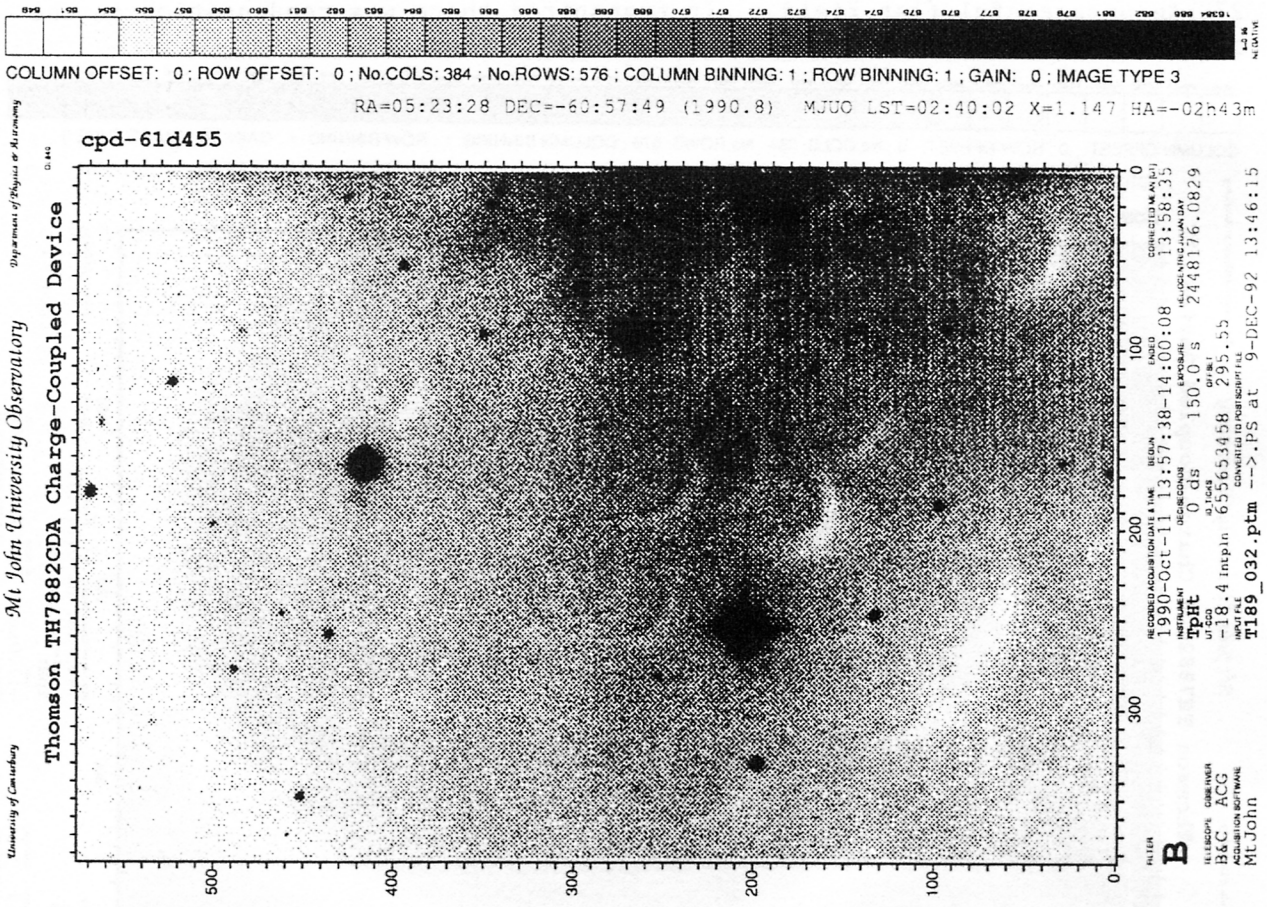
27. An unsuccesful flat field. It transpired there was condensation on the cryostat quartz entrance window.


COLUMN OFFSET: 0 ; ROW OFFSET: 0 ; No.COLS: 384 ; No.ROWS: 576 ; COLUMN BINNING: 1 ; ROW BINNING: 1 ; GAIN: 0 ; IMAGE TYPE 3
-DRK RA= DEC= (1992.5) MJUO LST=11:01:02 X= HA=
dome_flat dark center, bright edges
Mt John University Observatory
Thomson TH7882CDA Charge-Coupled Device
University of Canterbury
Department of Physics & Astronomy
1992-Jul-06 04:41:38-
60 ds
2448809.6955
04:41:30
TpHt
-11.0 Extrpn 710397698 304.79
T351_001.PTM -->.PS at 15-JUL-92 10:24:10
B
1f8 jpwt
MtJohn

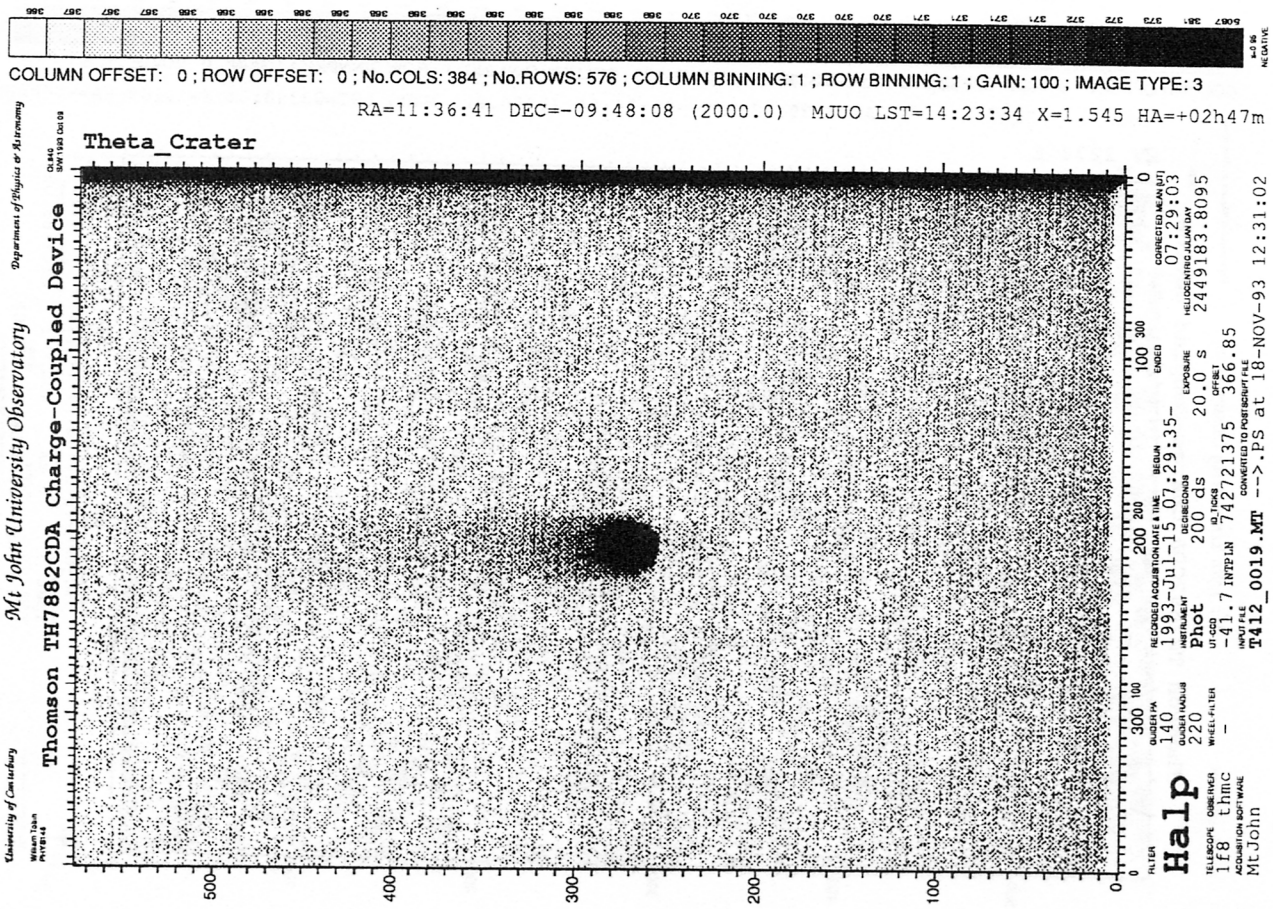
28. A flat-fielded science image probably affected by condensation.


COLUMN OFFSET: 0 ; ROW OFFSET: 0 ; No.COLS: 384 ; No.ROWS: 576 ; COLUMN BINNING: 1 ; ROW BINNING: 1 ; GAIN: 0 ; IMAGE TYPE 3
-DRK FLAT RA= DEC= (1990.6) MJUO LST=23:28:07 X= HA=
HV_12842 i
Mt John University Observatory
Thomson TH7882CDA Charge-Coupled Device
University of Canterbury
Department of Physics & Astronomy
I
B&C ACG
MtJohn
T159_017.ptm -->.PS at 15-DEC-92 13:19:20

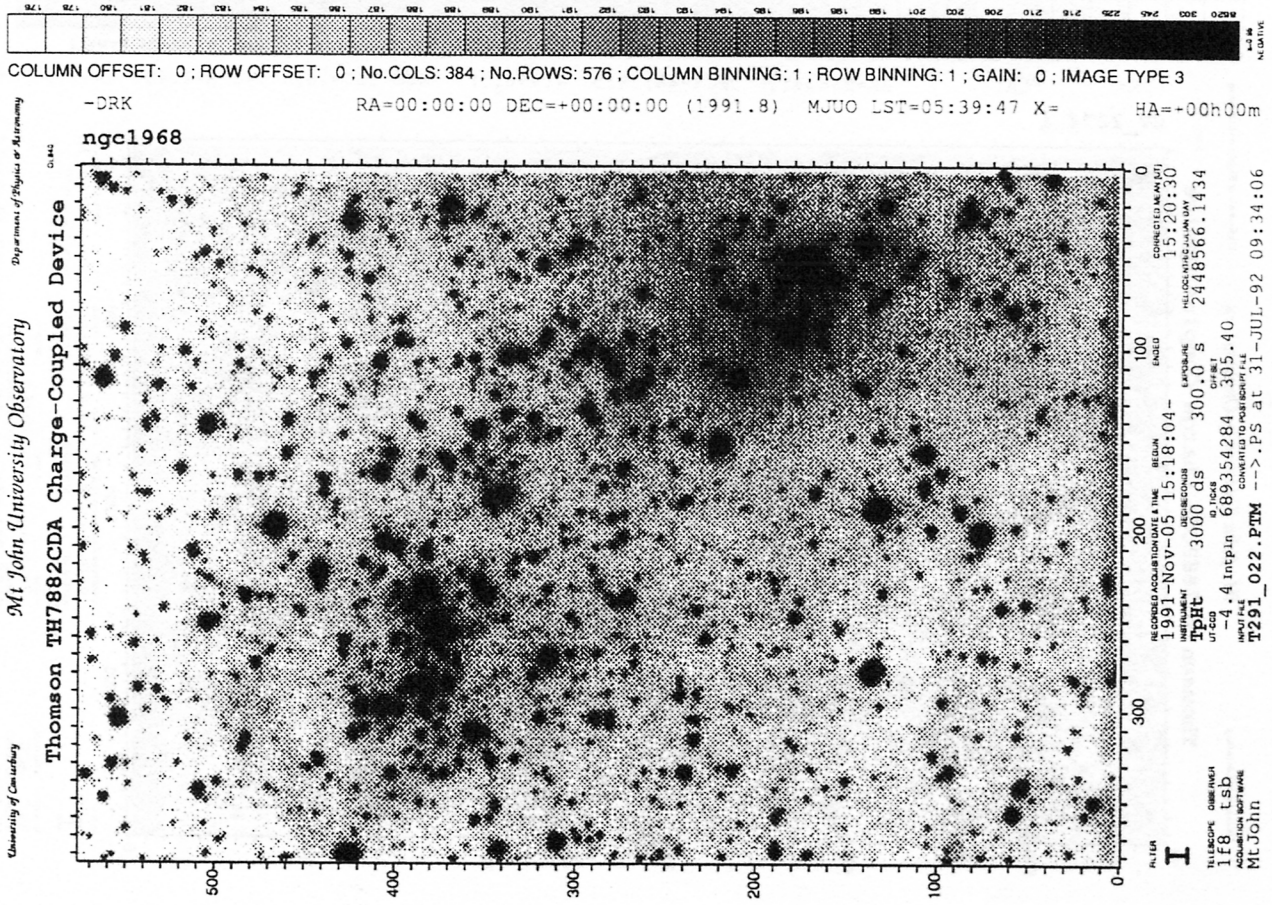
29. A non-flat-fielded image, possibly affected by condensation.


COLUMN OFFSET: 0 ; ROW OFFSET: 0 ; No.COLS: 384 ; No.ROWS: 576 ; COLUMN BINNING: 1 ; ROW BINNING: 1 ; GAIN: 0 ; IMAGE TYPE 3
RA=05:23:28 DEC=-60:57:49 (1990.8) MJUO LST=02:40:02 X=1.147 HA=-02h43m
cpd-61d455
Mt John University Observatory
Thomson TH7882CDA Charge-Coupled Device
University of Canterbury
Department of Physics & Astronomy
B
B&C ACG
MtJohn
T189_032.ptm -->.PS at 9-DEC-92 13:46:15

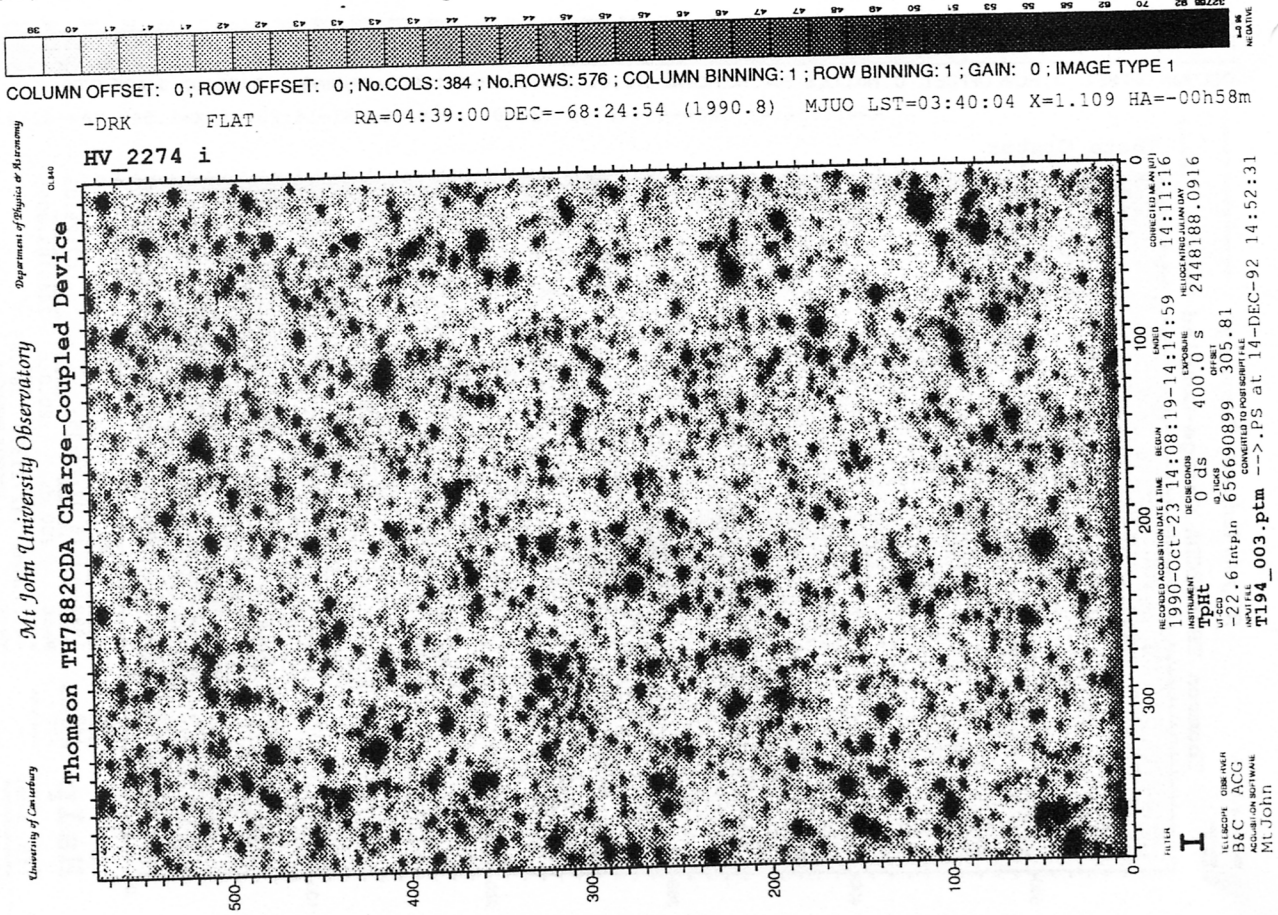
30. Flash-ring failure. Note the distinctiveness of the a.c. pickup and the smearing of the image due to reduced charge transfer efficiency.


COLUMN OFFSET: 0 ; ROW OFFSET: 0 ; No.COLS: 384 ; No.ROWS: 576 ; COLUMN BINNING: 1 ; ROW BINNING: 1 ; GAIN: 100 ; IMAGE TYPE: 3
RA=11:36:41 DEC=-09:48:08 (2000.0) MJUO LST=14:23:34 X=1.545 HA=+02h47m
Theta_Crater
Mt John University Observatory
Thomson TH7882CDA Charge-Coupled Device
Halp
T412_0019.MT

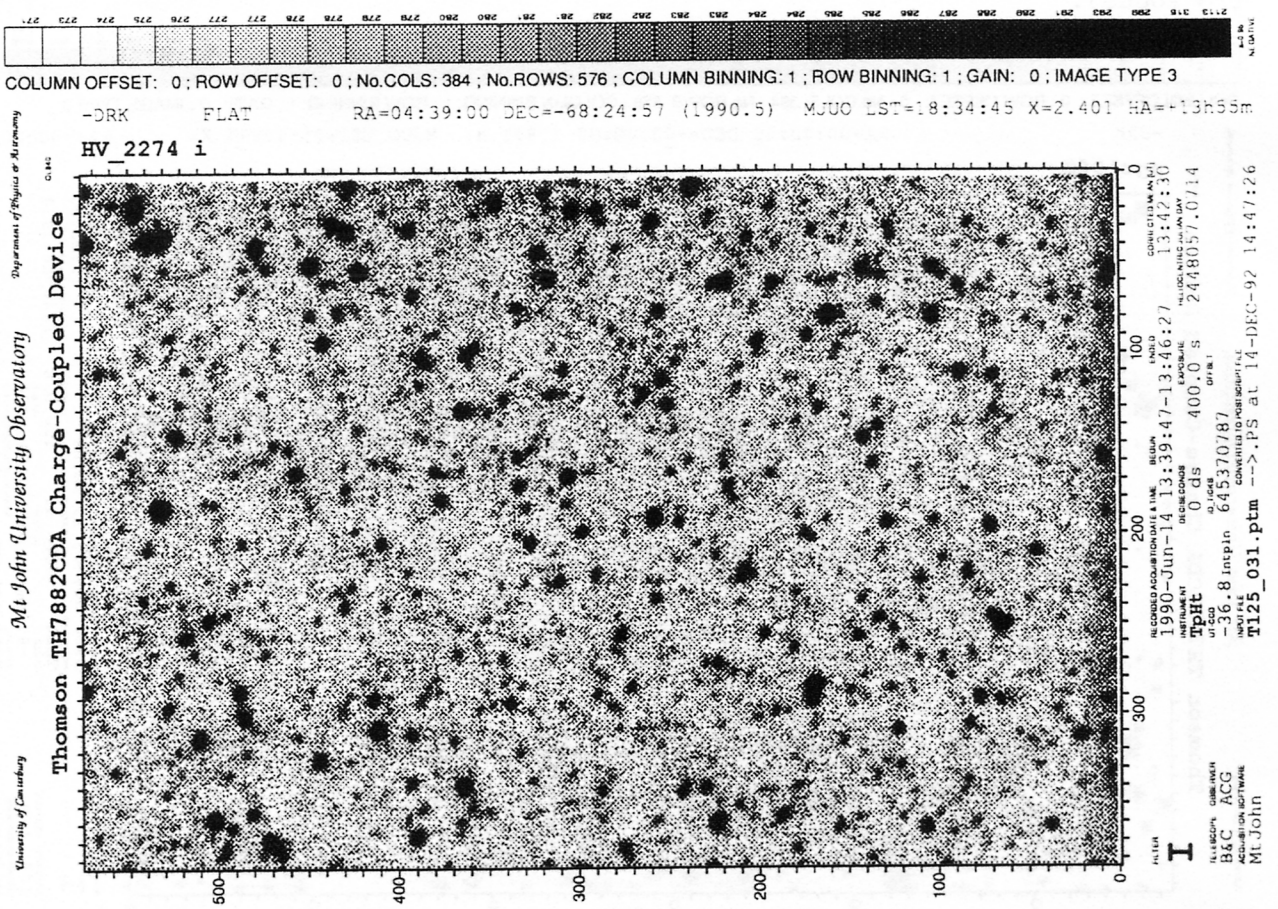
31. A science image acquired with good seeing (McLellan 1-metre telescope, f/8 focus).


COLUMN OFFSET: 0 ; ROW OFFSET: 0 ; No.COLS: 384 ; No.ROWS: 576 ; COLUMN BINNING: 1 ; ROW BINNING: 1 ; GAIN: 0 ; IMAGE TYPE 3
-DRK
RA=00:00:00 DEC=+00:00:00 (1991.8) MJUO LST=05:39:47 X= HA=+00h00m
ngc1968
Mt John University Observatory
Thomson TH7882CDA Charge-Coupled Device
I
T291_022.PTM

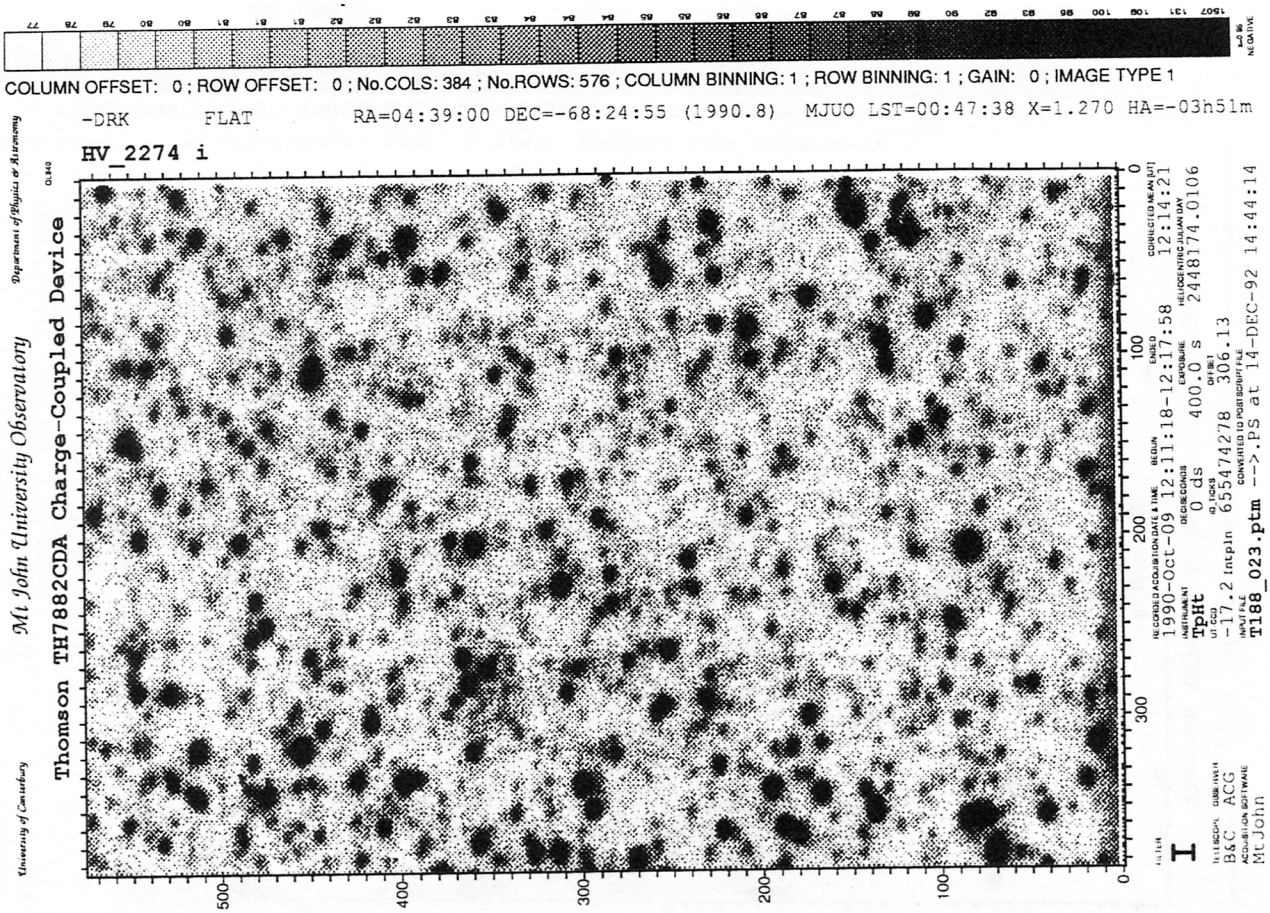
32. 1.6 arcsecond FWHM seeing (Boller & Chivens 0.6m telescope).


COLUMN OFFSET: 0 ; ROW OFFSET: 0 ; No.COLS: 384 ; No.ROWS: 576 ; COLUMN BINNING: 1 ; ROW BINNING: 1 ; GAIN: 0 ; IMAGE TYPE 1
-DRK FLAT RA=04:39:00 DEC=-68:24:54 (1990.8) MJUO LST=03:40:04 X=1.109 HA=-00h58m
HV_2274 i
Mt John University Observatory
Thomson TH7882CDA Charge-Coupled Device
University of Canterbury
Department of Physics & Astronomy
I
B&C ACG
Mt John
T194_003.ptm -->.PS at 14-DEC-92 14:52:31

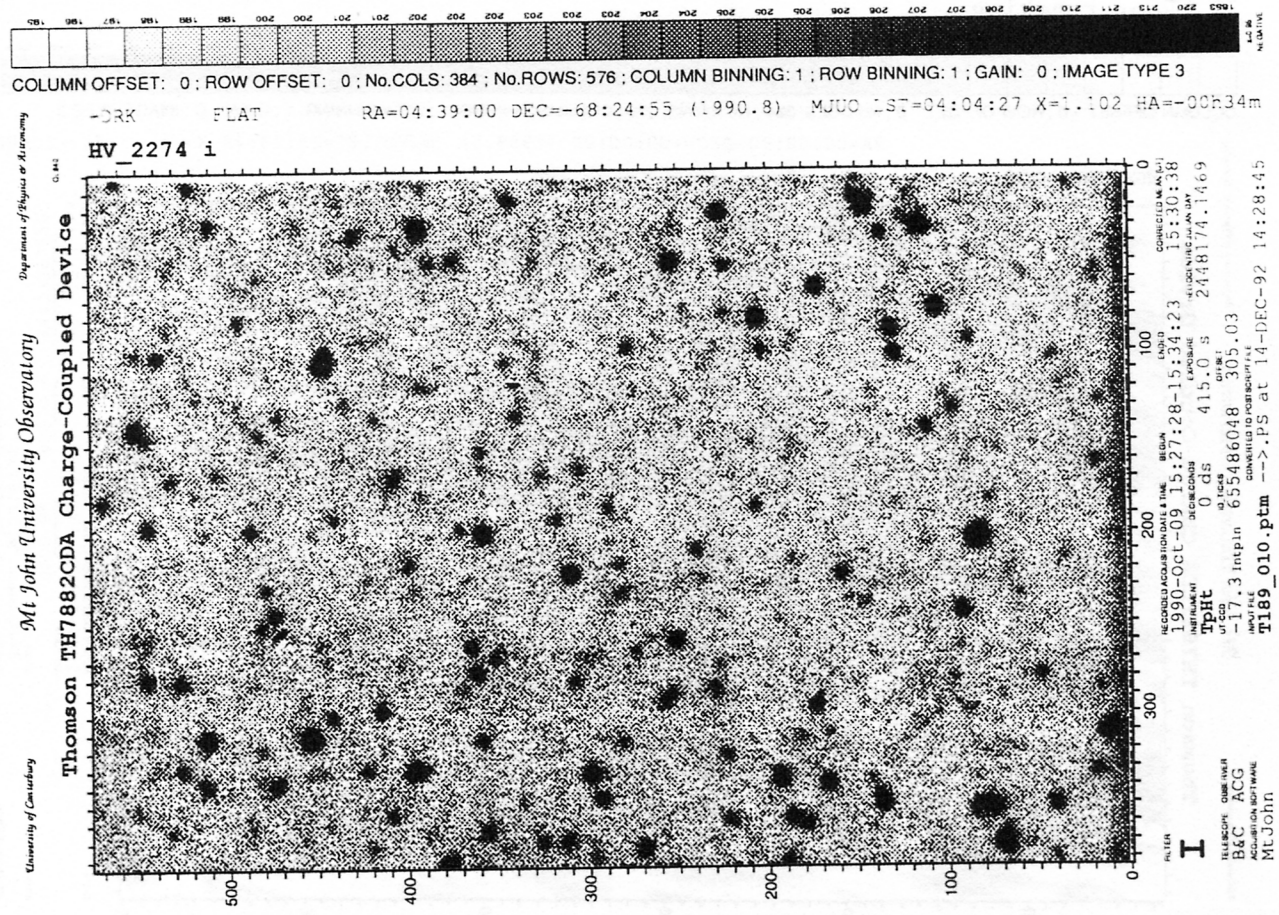
33. 2.3 arcsecond FWHM seeing (Boller & Chivens 0.6m telescope).


COLUMN OFFSET: 0 ; ROW OFFSET: 0 ; No.COLS: 384 ; No.ROWS: 576 ; COLUMN BINNING: 1 ; ROW BINNING: 1 ; GAIN: 0 ; IMAGE TYPE 3
-DRK FLAT RA=04:39:00 DEC=-68:24:57 (1990.5) MJUO LST=18:34:45 X=2.401 HA=+13h55m
HV_2274 i
Mt John University Observatory
Thomson TH7882CDA Charge-Coupled Device
University of Canterbury
Department of Physics & Astronomy
I
B&C ACG
Mt John
T125_031.ptm -->.PS at 14-DEC-92 14:47:26

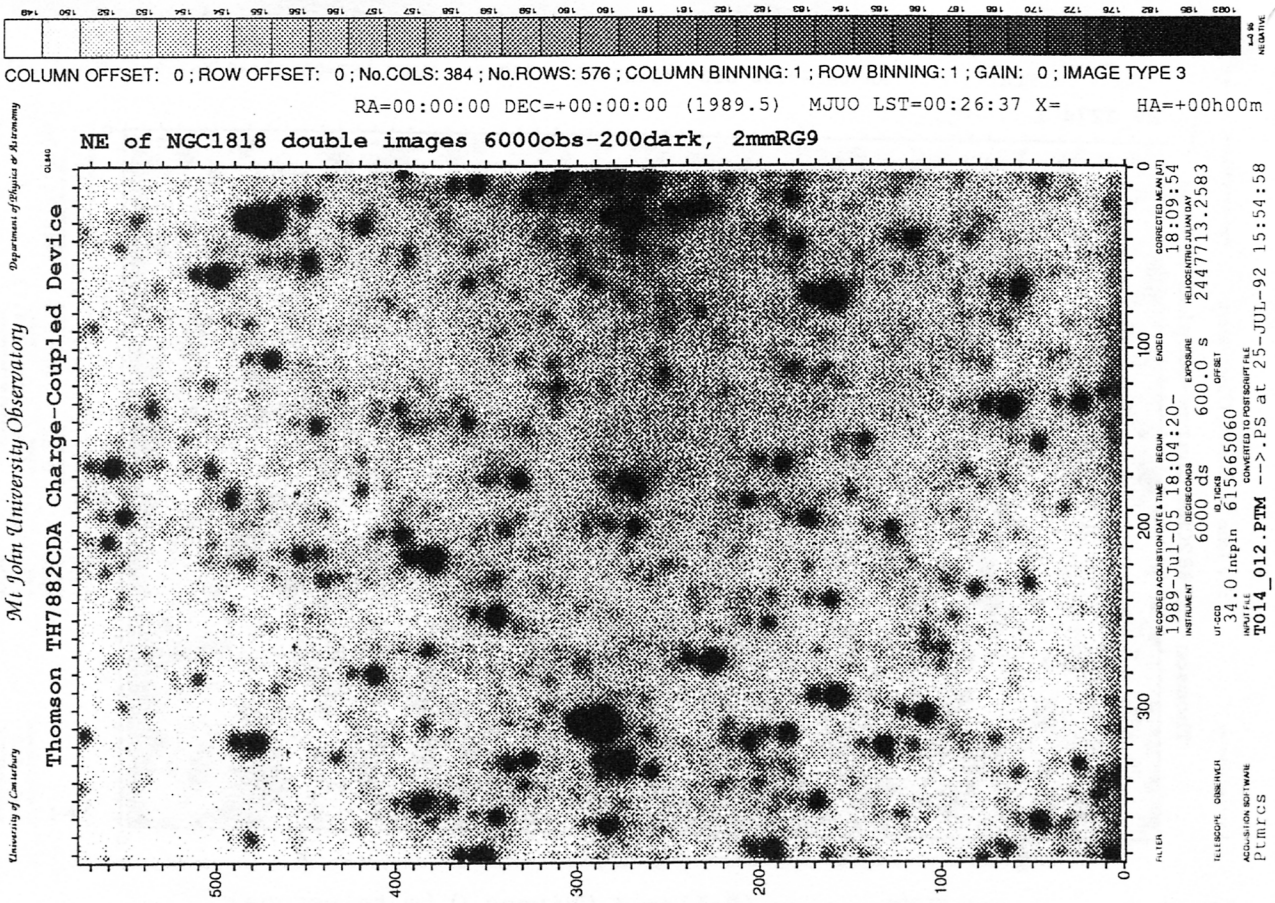
34. 3.1 arcsecond FWHM seeing (Boller & Chivens 0.6m telescope).


COLUMN OFFSET: 0 ; ROW OFFSET: 0 ; No.COLS: 384 ; No.ROWS: 576 ; COLUMN BINNING: 1 ; ROW BINNING: 1 ; GAIN: 0 ; IMAGE TYPE 1
-DRK FLAT RA=04:39:00 DEC=-68:24:55 (1990.8) MJUO LST=00:47:38 X=1.270 HA=-03h51m
HV_2274 i
Mt John University Observatory
Thomson TH7882CDA Charge-Coupled Device
University of Canterbury
1990-Oct-09 12:11:18-12:17:58 12:14:21
TpHt
0 ds 400.0 s 2448174.0106
-17.2 Intpln 65547427B 306.13
T188_023.ptm -->.PS at 14-DEC-92 14:44:14
I
B&C ACG
MtJohn

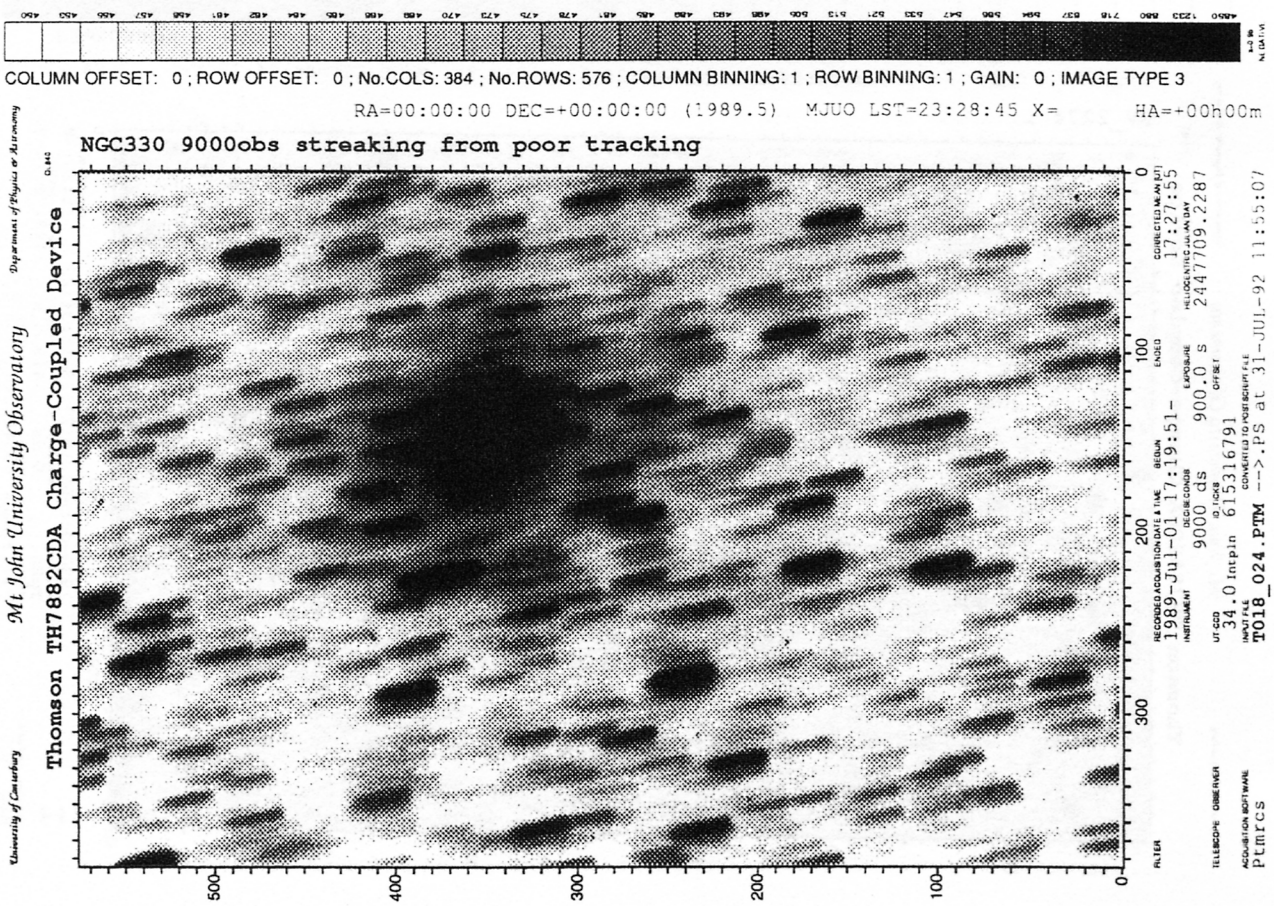
35. 4.0 arcsecond FWHM seeing (Boller & Chivens 0.6m telescope).


COLUMN OFFSET: 0 ; ROW OFFSET: 0 ; No.COLS: 384 ; No.ROWS: 576 ; COLUMN BINNING: 1 ; ROW BINNING: 1 ; GAIN: 0 ; IMAGE TYPE 3
-DRK FLAT RA=04:39:00 DEC=-68:24:55 (1990.8) MJUO LST=04:04:27 X=1.102 HA=-00h34m
HV_2274 i
Mt John University Observatory
Thomson TH7882CDA Charge-Coupled Device
University of Canterbury
1990-Oct-09 15:27:28-15:34:23 15:30:38
TpHt
0 ds 415.0 s 2448174.1469
-17.3 Intpln 65548604B 305.03
T189_010.ptm -->.PS at 14-DEC-92 14:28:45
I
B&C ACG
MtJohn

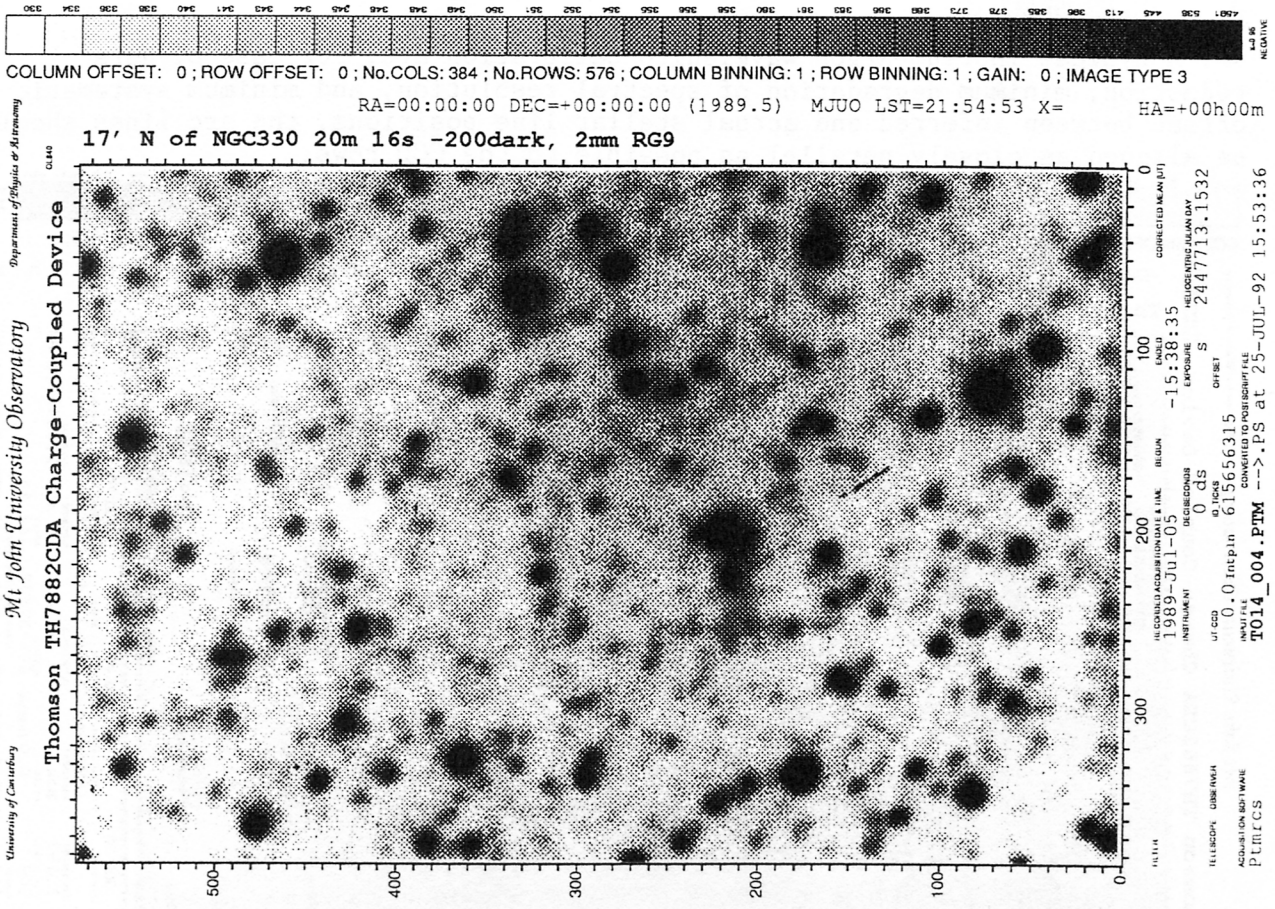
36. The 0.6m Boller & Chivens telescope jumped as it passed through the meridian.


COLUMN OFFSET: 0 ; ROW OFFSET: 0 ; No.COLS: 384 ; No.ROWS: 576 ; COLUMN BINNING: 1 ; ROW BINNING: 1 ; GAIN: 0 ; IMAGE TYPE 3
RA=00:00:00 DEC=+00:00:00 (1989.5) MJUO LST=00:26:37 X= HA=+00h00m
NE of NGC1818 double images 6000obs-200dark, 2mmRG9
Mt John University Observatory
Thomson TH7882CDA Charge-Coupled Device
University of Canterbury
Department of Physics & Astronomy
1989-Jul-05 18:04:20-
6000 ds
600.0 s
18:09:54
2447713.2583
34.0 Intpln 615665060
T014_012.PTM -->.PS at 25-JUL-92 15:54:58
Ptmrcs

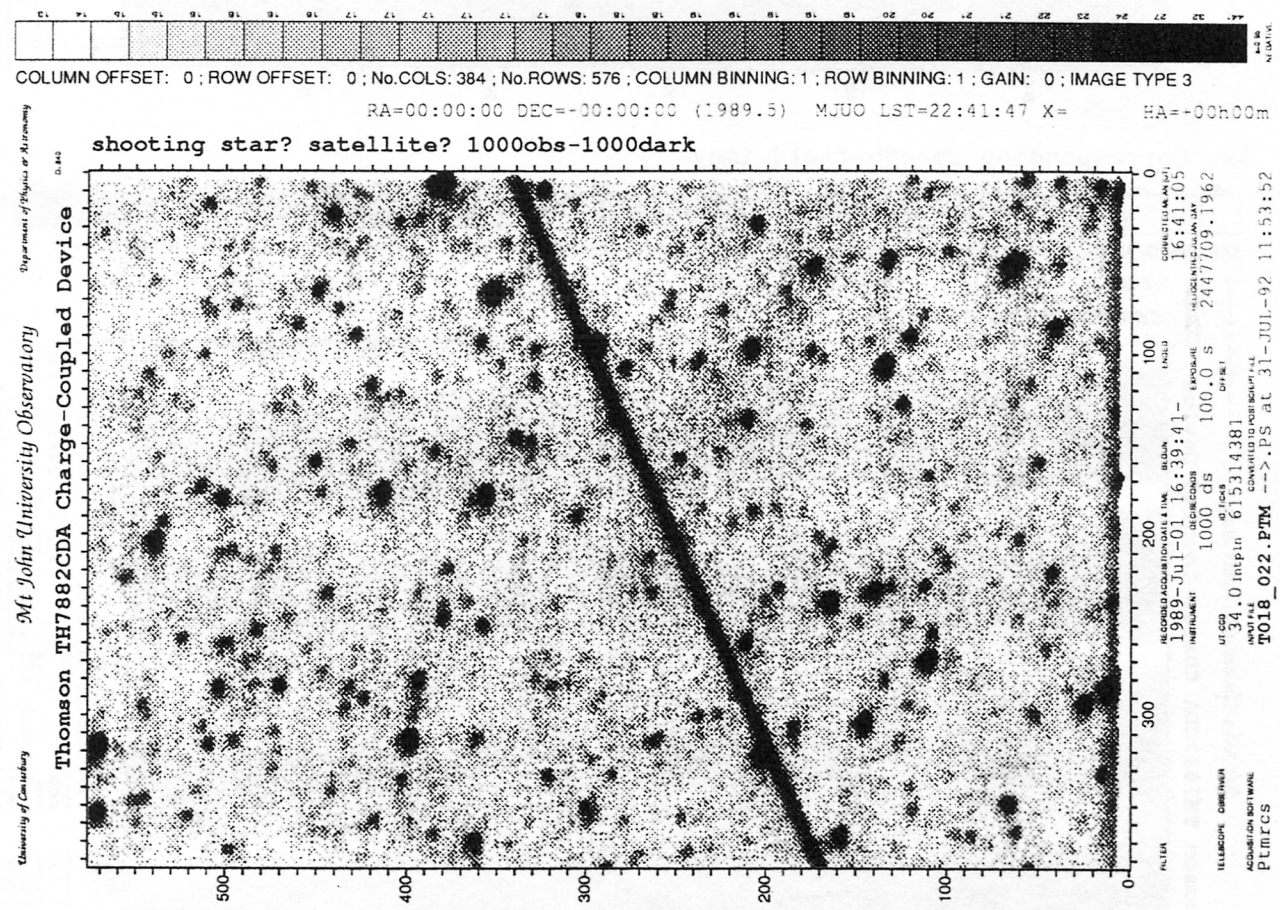
37. Poor tracking.


COLUMN OFFSET: 0 ; ROW OFFSET: 0 ; No.COLS: 384 ; No.ROWS: 576 ; COLUMN BINNING: 1 ; ROW BINNING: 1 ; GAIN: 0 ; IMAGE TYPE 3
RA=00:00:00 DEC=+00:00:00 (1989.5) MJUO LST=23:28:45 X= HA=+00h00m
NGC330 9000obs streaking from poor tracking
Mt John University Observatory
Thomson TH7882CDA Charge-Coupled Device
University of Canterbury
Department of Physics & Astronomy
1989-Jul-01 17:19:51-
9000 ds
900.0 s
17:27:55
2447709.2287
34.0 Intpln 615316791
T018_024.PTM -->.PS at 31-JUL-92 11:55:07
Ptmrcs

38. A cosmic ray that passed through the chip at a low angle.

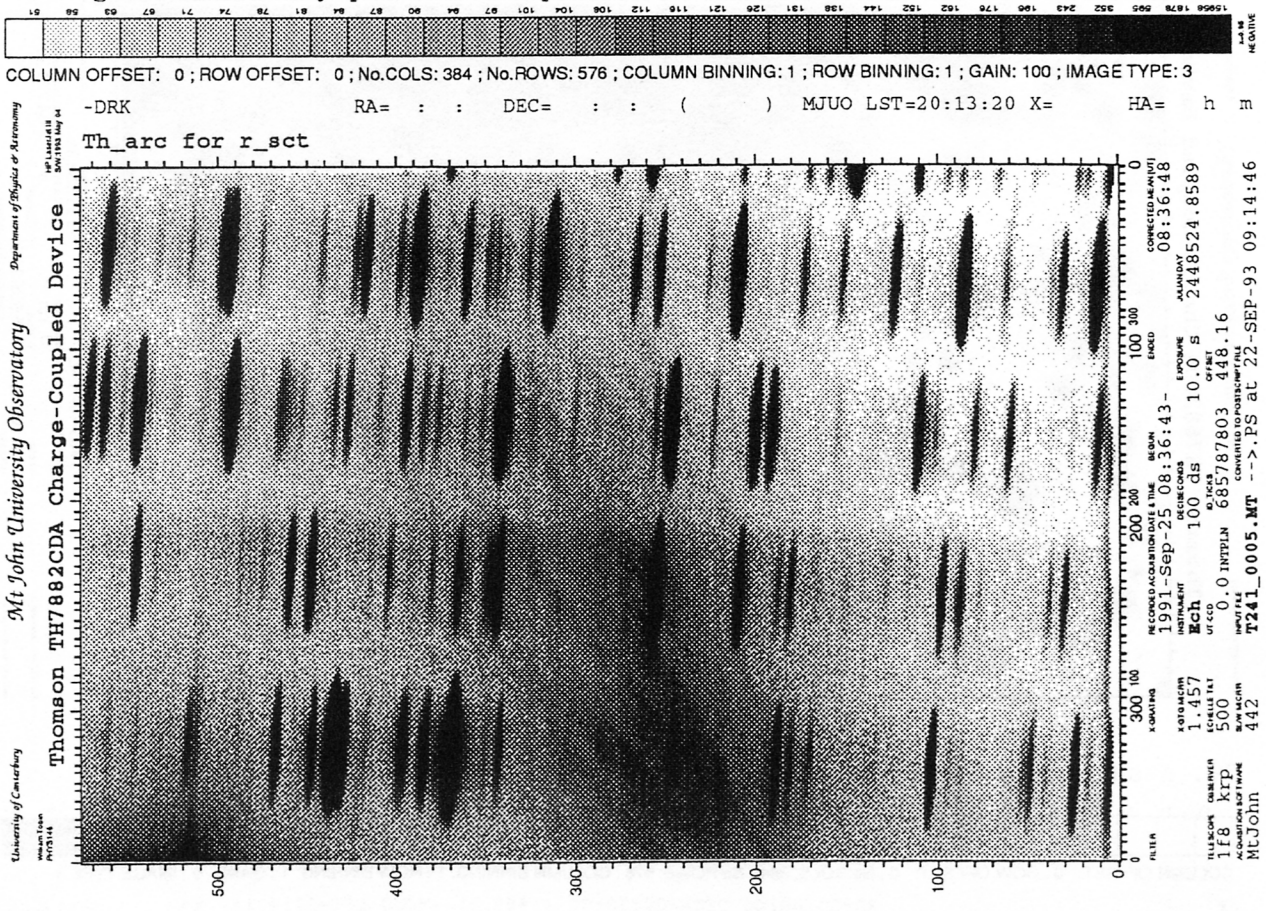

COLUMN OFFSET: 0 ; ROW OFFSET: 0 ; No.COLS: 384 ; No.ROWS: 576 ; COLUMN BINNING: 1 ; ROW BINNING: 1 ; GAIN: 0 ; IMAGE TYPE 3
RA=00:00:00 DEC=+00:00:00 (1989.5) MJUO LST=21:54:53 X= HA=+00h00m
17' N of NGC330 20m 16s -200dark, 2mm RG9
Mt John University Observatory
Thomson TH7882CDA Charge-Coupled Device
University of Canterbury
Department of Physics & Astronomy
1989-Jul-05
-15:38:35
0 ds
2447713.1532
0.0 Intpln
615656315
T014_004.PTM -->.PS at 25-JUL-92 15:53:36
Ptmrcs

39. A satellite trail.

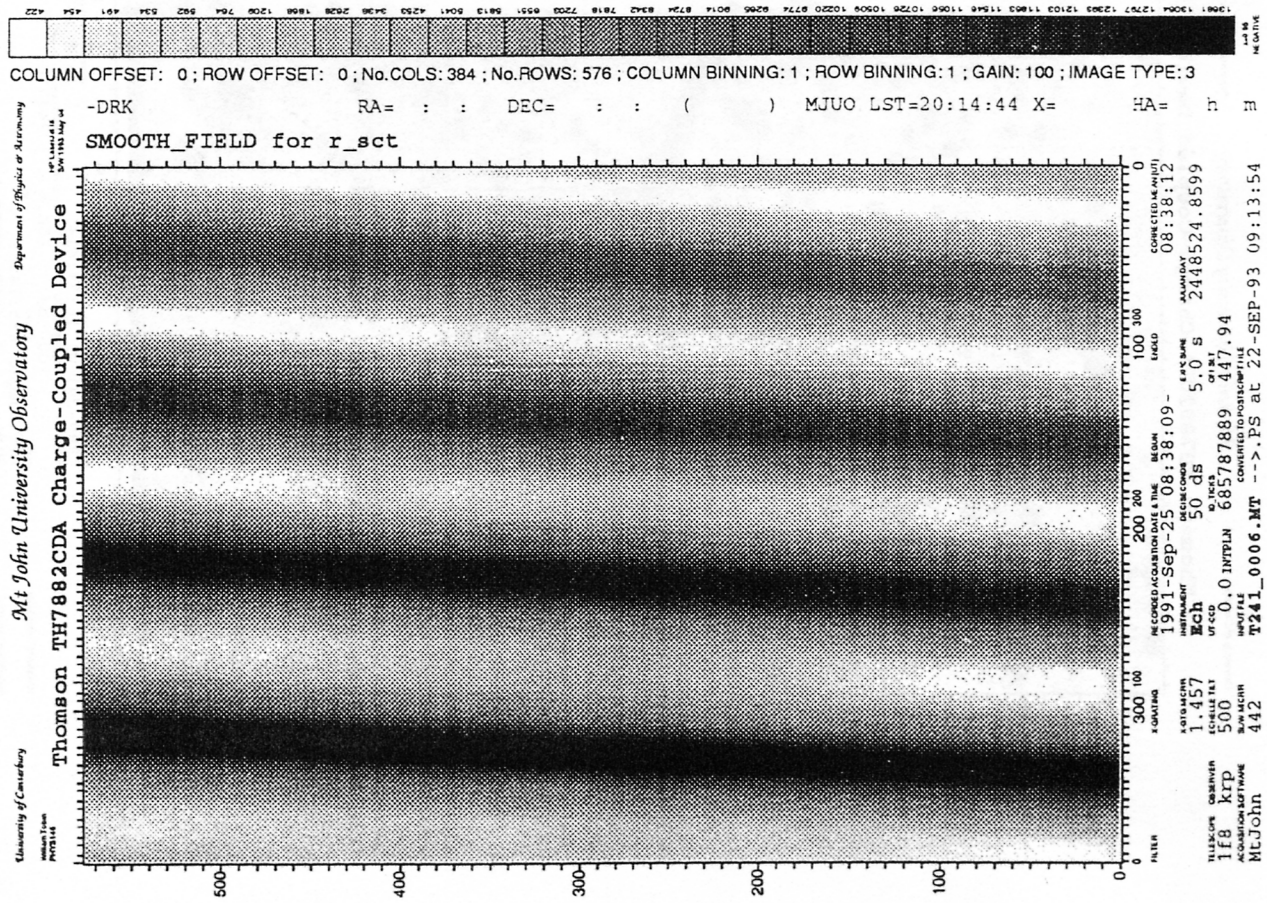

COLUMN OFFSET: 0 ; ROW OFFSET: 0 ; No.COLS: 384 ; No.ROWS: 576 ; COLUMN BINNING: 1 ; ROW BINNING: 1 ; GAIN: 0 ; IMAGE TYPE 3
RA=00:00:00 DEC=+00:00:00 (1989.5) MJUO LST=22:41:47 X= HA=+00h00m
shooting star? satellite? 1000obs-1000dark
Mt John University Observatory
Thomson TH7882CDA Charge-Coupled Device
University of Canterbury
Department of Physics & Astronomy
1989-Jul-01 16:39:41-
1000 ds
100.0 s
2447709.1962
34.0 Intpln
615314381
T018_022.PTM -->.PS at 31-JUL-92 11:53:52
Ptmrcs

D. ECHELLE SPECTROSCOPY.

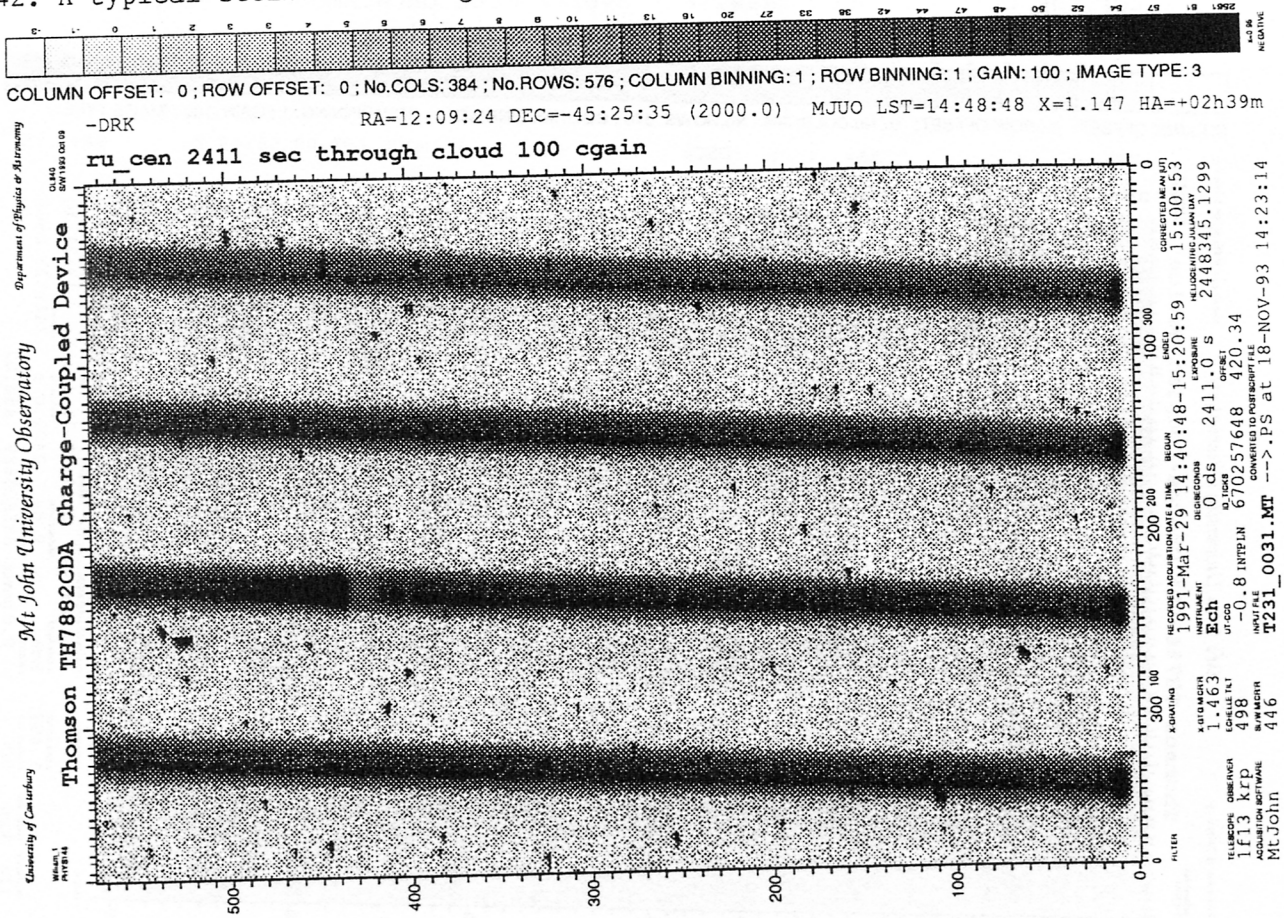
40. A typical Thorium-Argon wavelength calibration arc. For ease of data reduction, minimum degradation of spectral resolution, and minimum systematic offset between inferred and actual stellar line positions, the arc lines should be aligned as closely parallel as possible to the CCD rows.


COLUMN OFFSET: 0 ; ROW OFFSET: 0 ; No.COLS: 384 ; No.ROWS: 576 ; COLUMN BINNING: 1 ; ROW BINNING: 1 ; GAIN: 100 ; IMAGE TYPE: 3
-DRK RA= : : DEC= : : ( ) MJUO LST=20:13:20 X= HA= h m
Th_arc for r_sct
Mt John University Observatory
Thomson TH7882CDA Charge-Coupled Device
University of Canterbury
Department of Physics & Astronomy
1991-Sep-25 08:36:43-
08:36:48
2448524.8589
T241_0005.MT -->.PS at 22-SEP-93 09:14:46
MtJohn

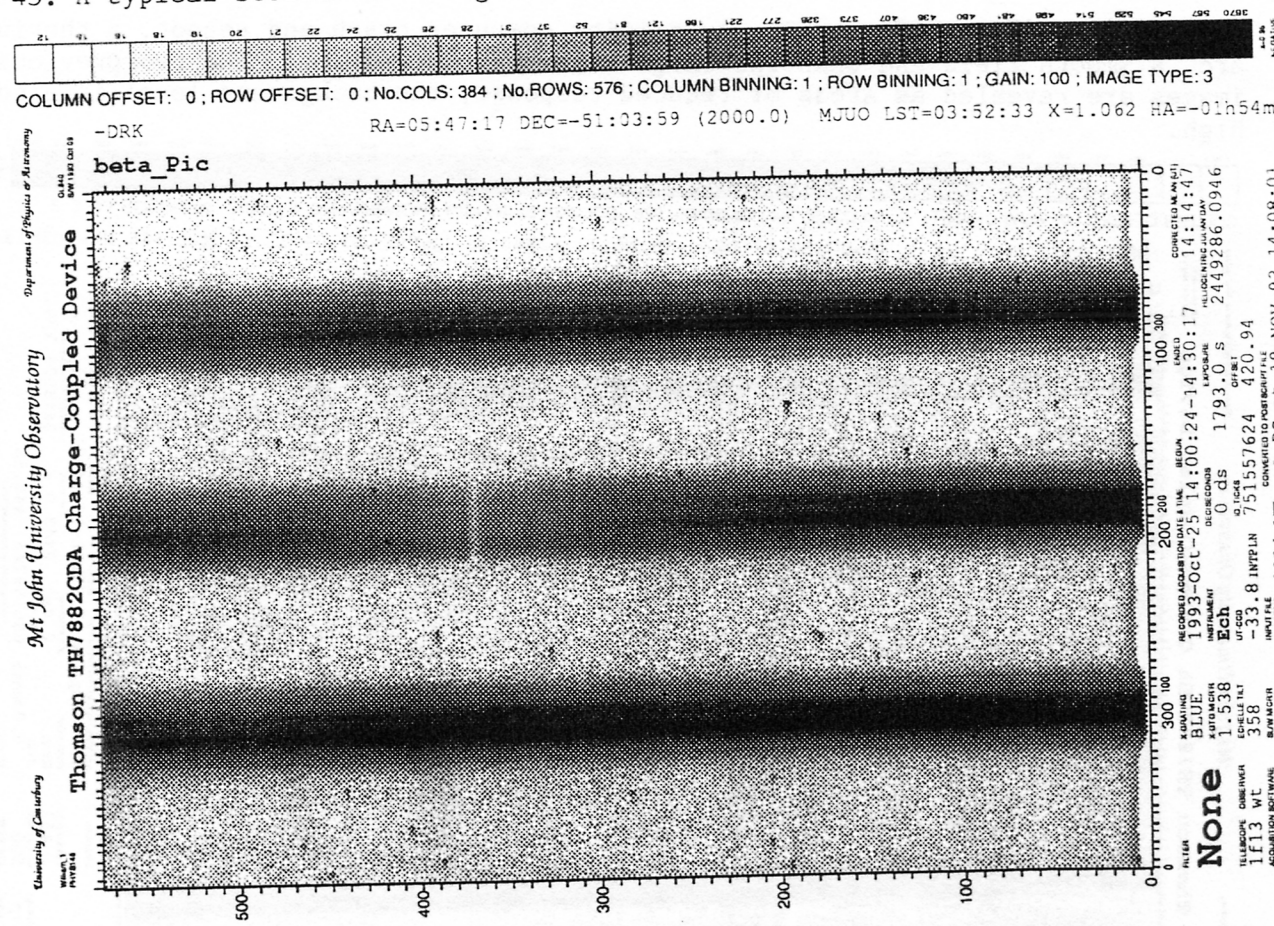
41. Corresponding smooth-field image.


COLUMN OFFSET: 0 ; ROW OFFSET: 0 ; No.COLS: 384 ; No.ROWS: 576 ; COLUMN BINNING: 1 ; ROW BINNING: 1 ; GAIN: 100 ; IMAGE TYPE: 3
-DRK RA= : : DEC= : : ( ) MJUO LST=20:14:44 X= HA= h m
SMOOTH_FIELD for r_sct
Mt John University Observatory
Thomson TH7882CDA Charge-Coupled Device
University of Canterbury
Department of Physics & Astronomy
1991-Sep-25 08:38:09-
08:38:12
2448524.8599
T241_0006.MT -->.PS at 22-SEP-93 09:13:54
MtJohn

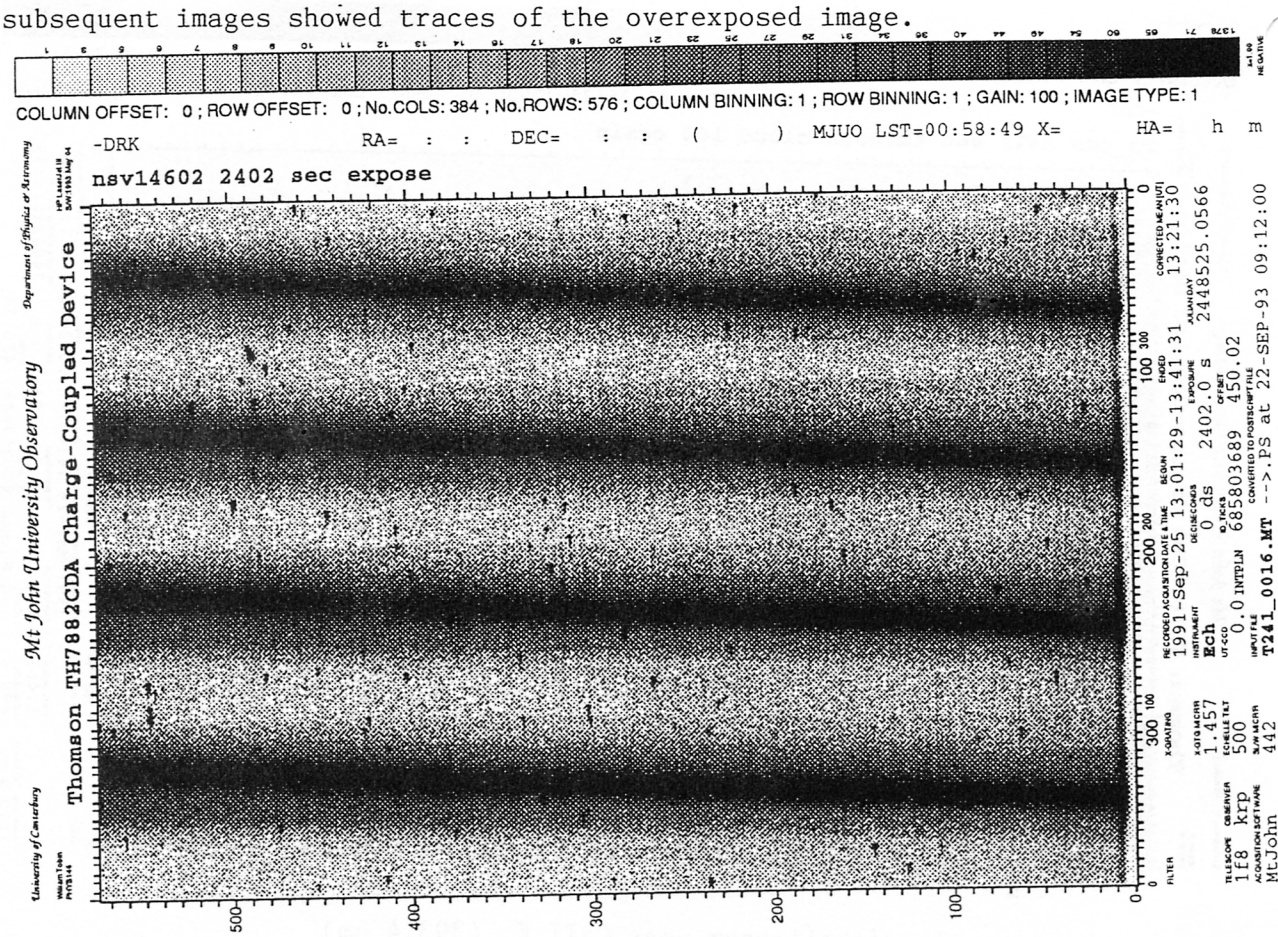
42. A typical stellar échellogram near Hα. (656.3 nm)


COLUMN OFFSET: 0 ; ROW OFFSET: 0 ; No.COLS: 384 ; No.ROWS: 576 ; COLUMN BINNING: 1 ; ROW BINNING: 1 ; GAIN: 100 ; IMAGE TYPE: 3
-DRK
RA=12:09:24 DEC=-45:25:35 (2000.0) MJUO LST=14:48:48 X=1.147 HA=+02h39m
ru_cen 2411 sec through cloud 100 cgain
Mt John University Observatory
Thomson TH7882CDA Charge-Coupled Device
University of Canterbury
Department of Physics & Astronomy
Ech
1991-Mar-29 14:40:48-15:20:59
2411.0 s
2448345.1299
670257648
420.34
1.463
498
446
T231_0031.MT -->.PS at 18-NOV-93 14:23:14
MtJohn

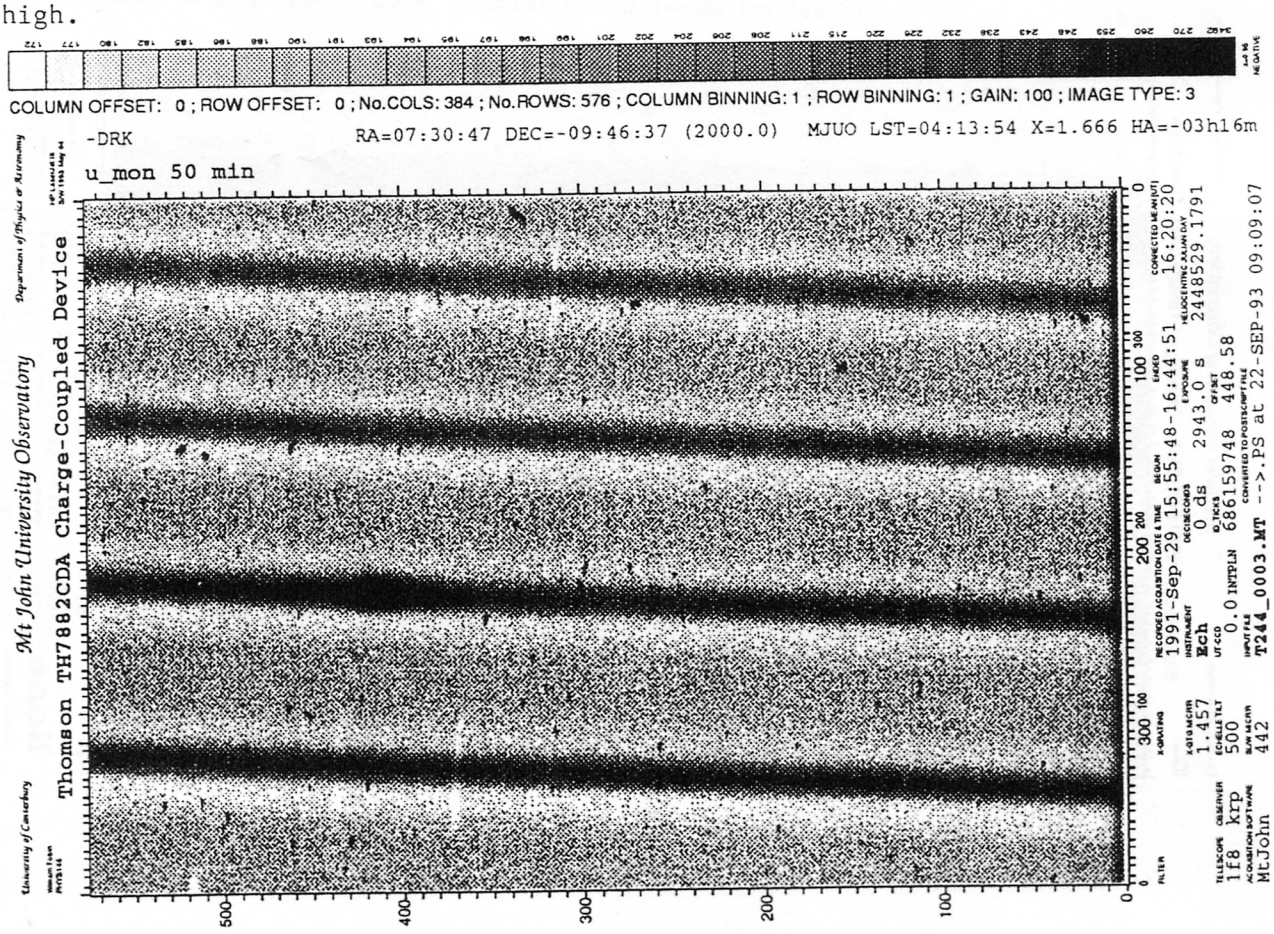
43. A typical stellar échellogram near CaII K. (393.4 nm)



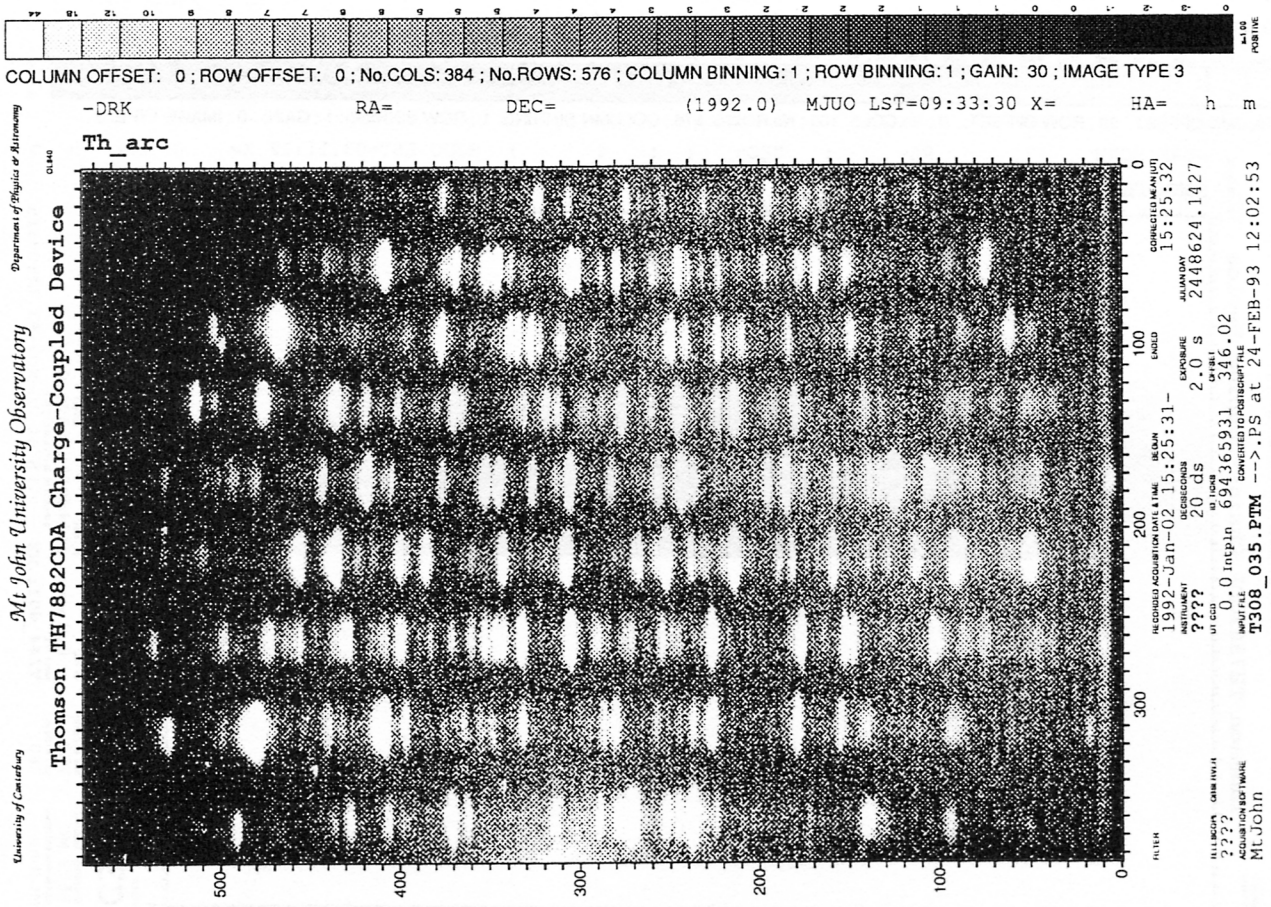
44. After the chip had been massively overexposed on a smooth field, subsequent images showed traces of the overexposed image.


COLUMN OFFSET: 0 ; ROW OFFSET: 0 ; No.COLS: 384 ; No.ROWS: 576 ; COLUMN BINNING: 1 ; ROW BINNING: 1 ; GAIN: 100 ; IMAGE TYPE: 1
-DRK RA= : : DEC= : : ( ) MJUO LST=00:58:49 X= HA= h m
nsv14602 2402 sec expose
Mt John University Observatory
Thomson TH7882CDA Charge-Coupled Device
University of Canterbury
Department of Physics & Astronomy
1991-Sep-25 13:01:29-13:41:31
2402.0 s
2448525.0566
685803689
450.02
T241_0016.MT -->.PS at 22-SEP-93 09:12:00
1f8 krp
MtJohn
1.457
500
442

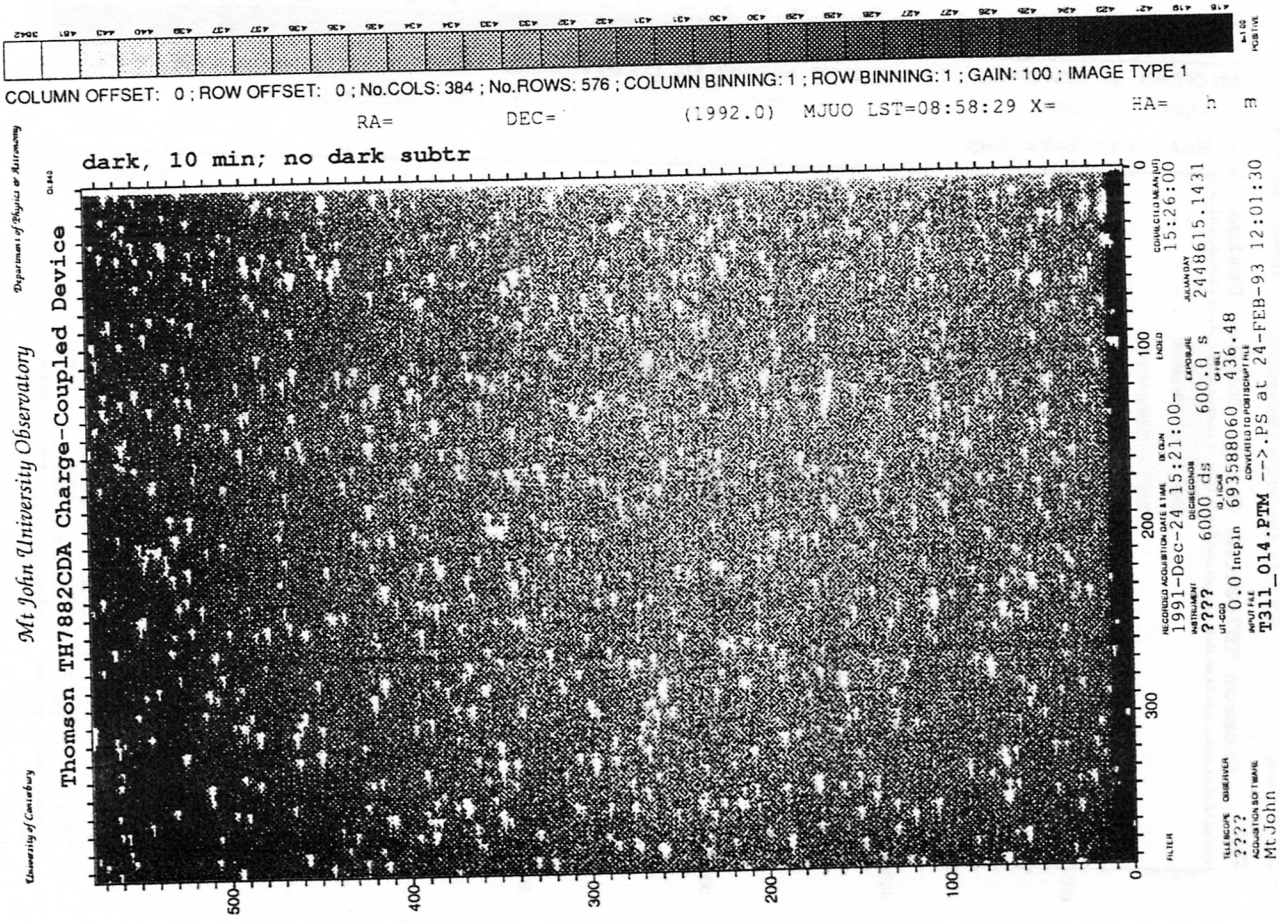
45. After an 'Error 38' static-electricity computer crash and reboot, a thorium arc, a smooth field and then the image below were acquired. The two previous images are revealed as areas of reduced response; the background level is also high.



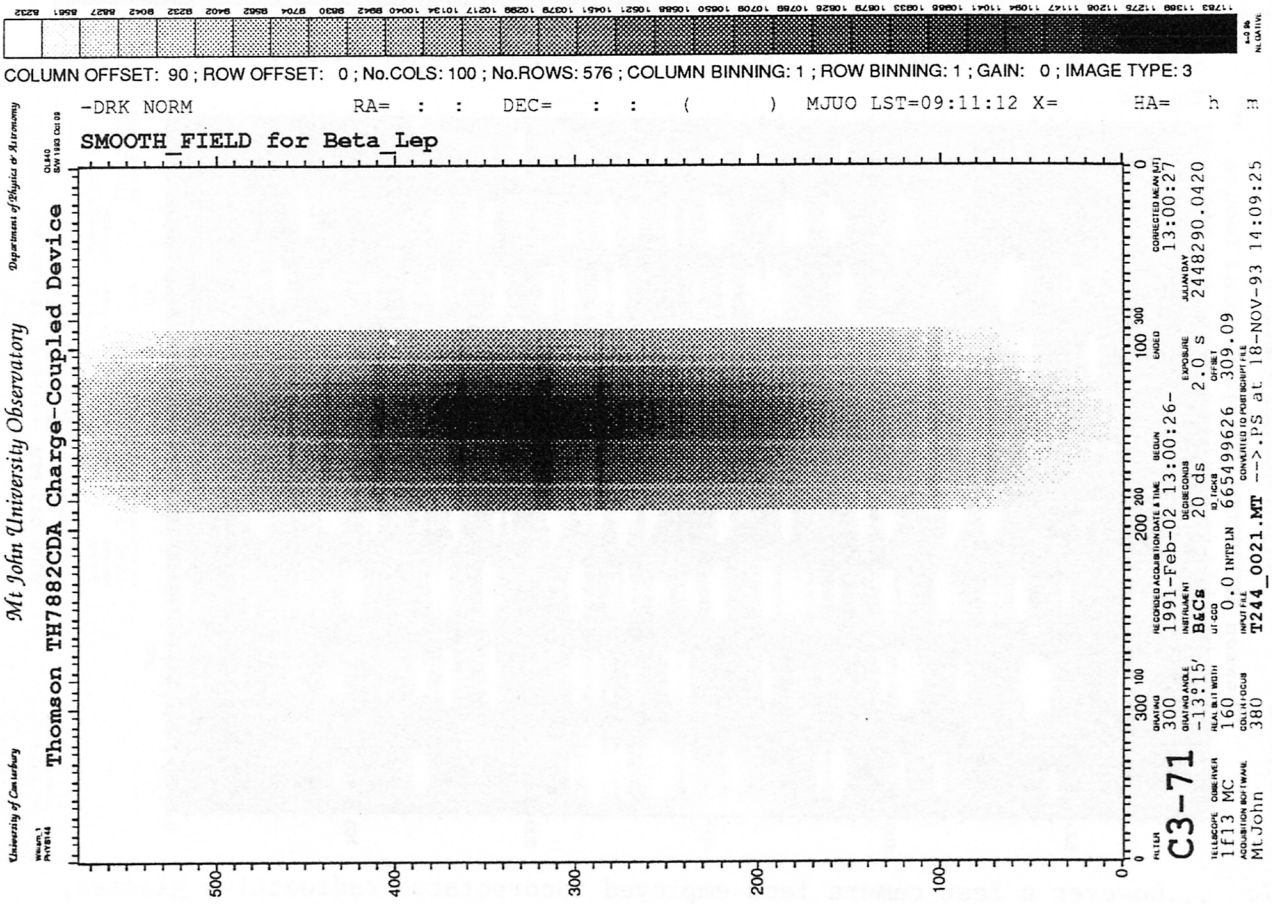
46. An overseas user tried adding a focal converter to the échelle spectrograph in order to obtain more orders...


COLUMN OFFSET: 0 ; ROW OFFSET: 0 ; No.COLS: 384 ; No.ROWS: 576 ; COLUMN BINNING: 1 ; ROW BINNING: 1 ; GAIN: 30 ; IMAGE TYPE 3
-DRK RA= DEC= (1992.0) MJUO LST=09:33:30 X= HA=
Th_arc
Mt John University Observatory
Thomson TH7882CDA Charge-Coupled Device
University of Canterbury
1992-Jan-02 15:25:31-
20 ds
2.0 s
2448624.1427
694365931 346.02
T308_035.PTM -->.PS at 24-FEB-93 12:02:53
15:25:32
Mt.John

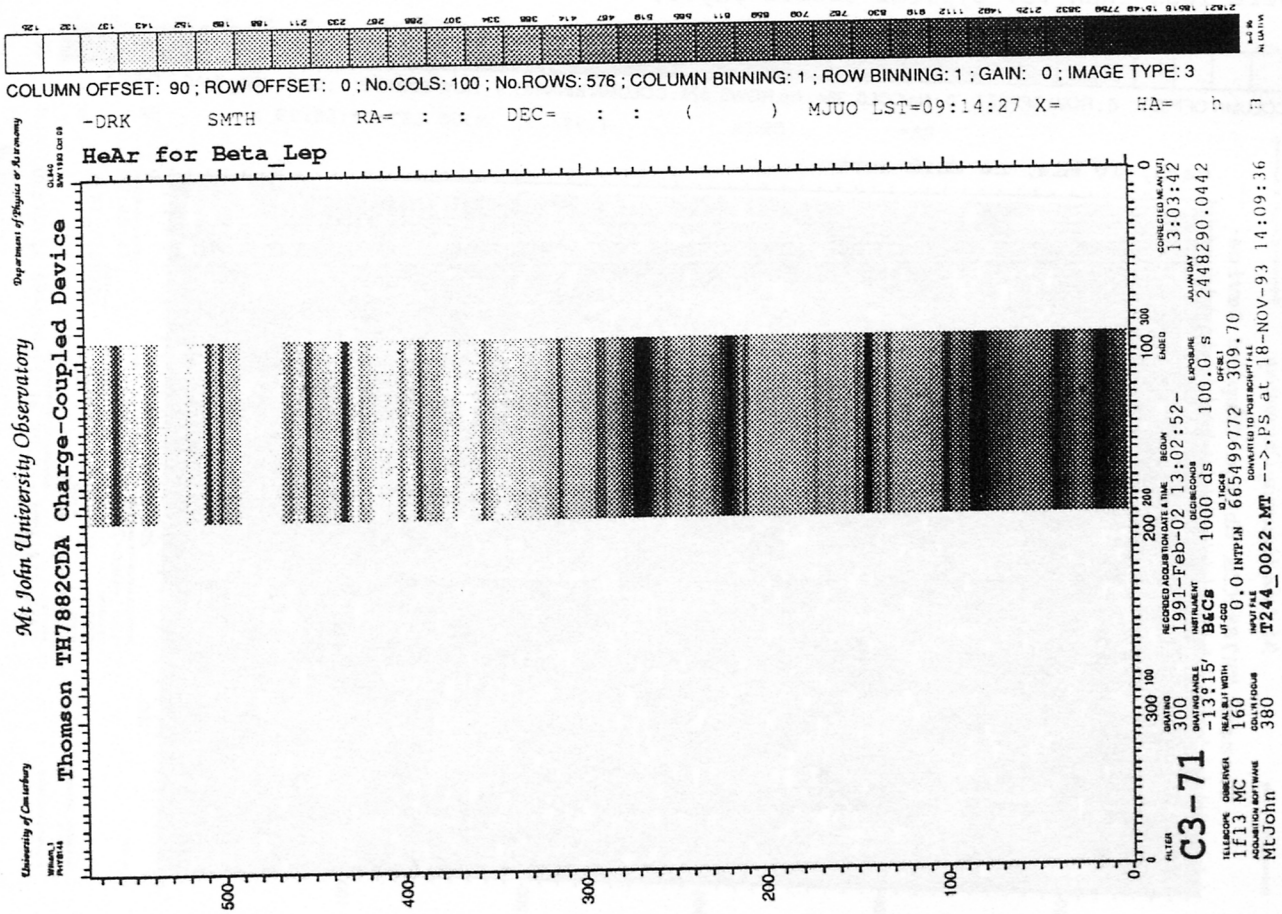
47. ...however a fast camera lens employed incorporated radioactive glasses, which enormously increased the particle-event rate. (The charges deposited were less than for typical cosmic rays.)


COLUMN OFFSET: 0 ; ROW OFFSET: 0 ; No.COLS: 384 ; No.ROWS: 576 ; COLUMN BINNING: 1 ; ROW BINNING: 1 ; GAIN: 100 ; IMAGE TYPE 1
RA= DEC= (1992.0) MJUO LST=08:58:29 X= HA=
dark, 10 min; no dark subtr
Mt John University Observatory
Thomson TH7882CDA Charge-Coupled Device
University of Canterbury
1991-Dec-24 15:21:00-
6000 ds
600.0 s
2448615.1431
693588060 436.48
T311_014.PTM -->.PS at 24-FEB-93 12:01:30
15:26:00
Mt.John

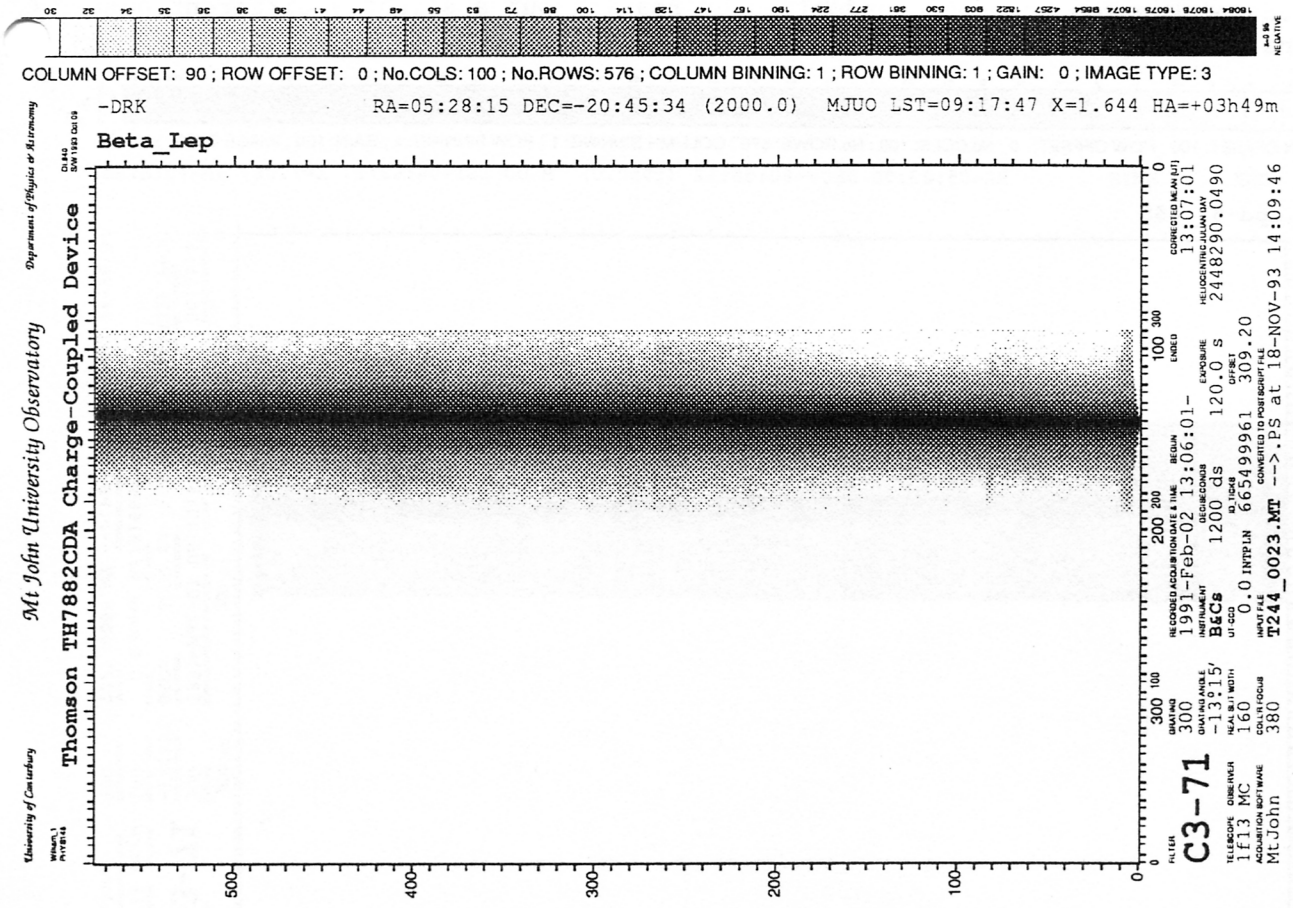
48.Typical smooth field. The illumination is unfortunately not flat along the slit length, which hinders accurate sky subtraction.


COLUMN OFFSET: 90 ; ROW OFFSET: 0 ; No.COLS: 100 ; No.ROWS: 576 ; COLUMN BINNING: 1 ; ROW BINNING: 1 ; GAIN: 0 ; IMAGE TYPE: 3
-DRK NORM RA= : : DEC= : : ( ) MJUO LST=09:11:12 X= HA=
SMOOTH_FIELD for Beta_Lep
Mt John University Observatory
Thomson TH7882CDA Charge-Coupled Device
C3-71
1991-Feb-02 13:00:26
T244_0021.MT
18-NOV-93 14:09:25

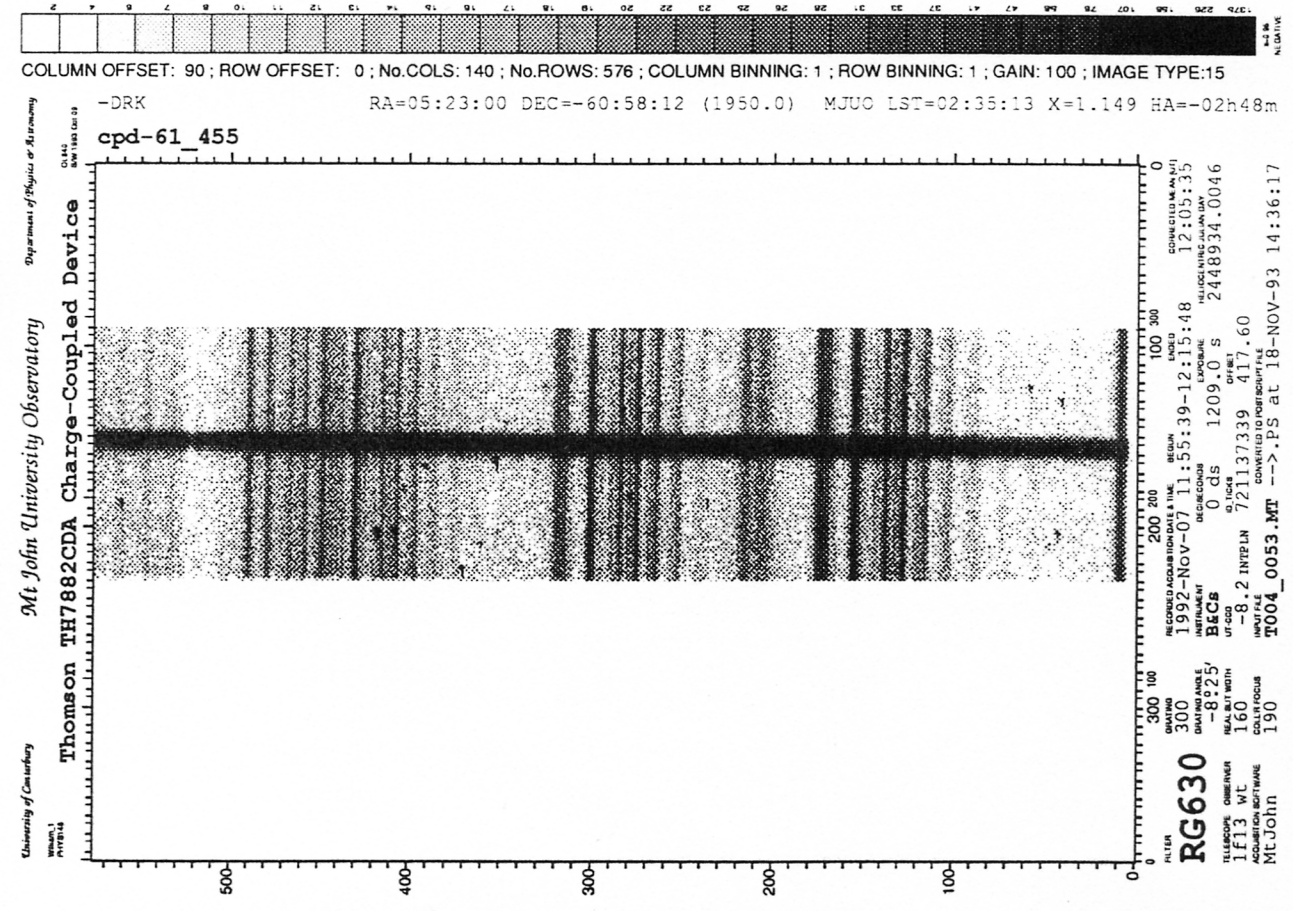
49. Typical wavelength calibration arc.


COLUMN OFFSET: 90 ; ROW OFFSET: 0 ; No.COLS: 100 ; No.ROWS: 576 ; COLUMN BINNING: 1 ; ROW BINNING: 1 ; GAIN: 0 ; IMAGE TYPE: 3
-DRK SMTH RA= : : DEC= : : ( ) MJUO LST=09:14:27 X= HA=
HeAr for Beta_Lep
Mt John University Observatory
Thomson TH7882CDA Charge-Coupled Device
C3-71
1991-Feb-02 13:02:52
T244_0022.MT
18-NOV-93 14:09:36

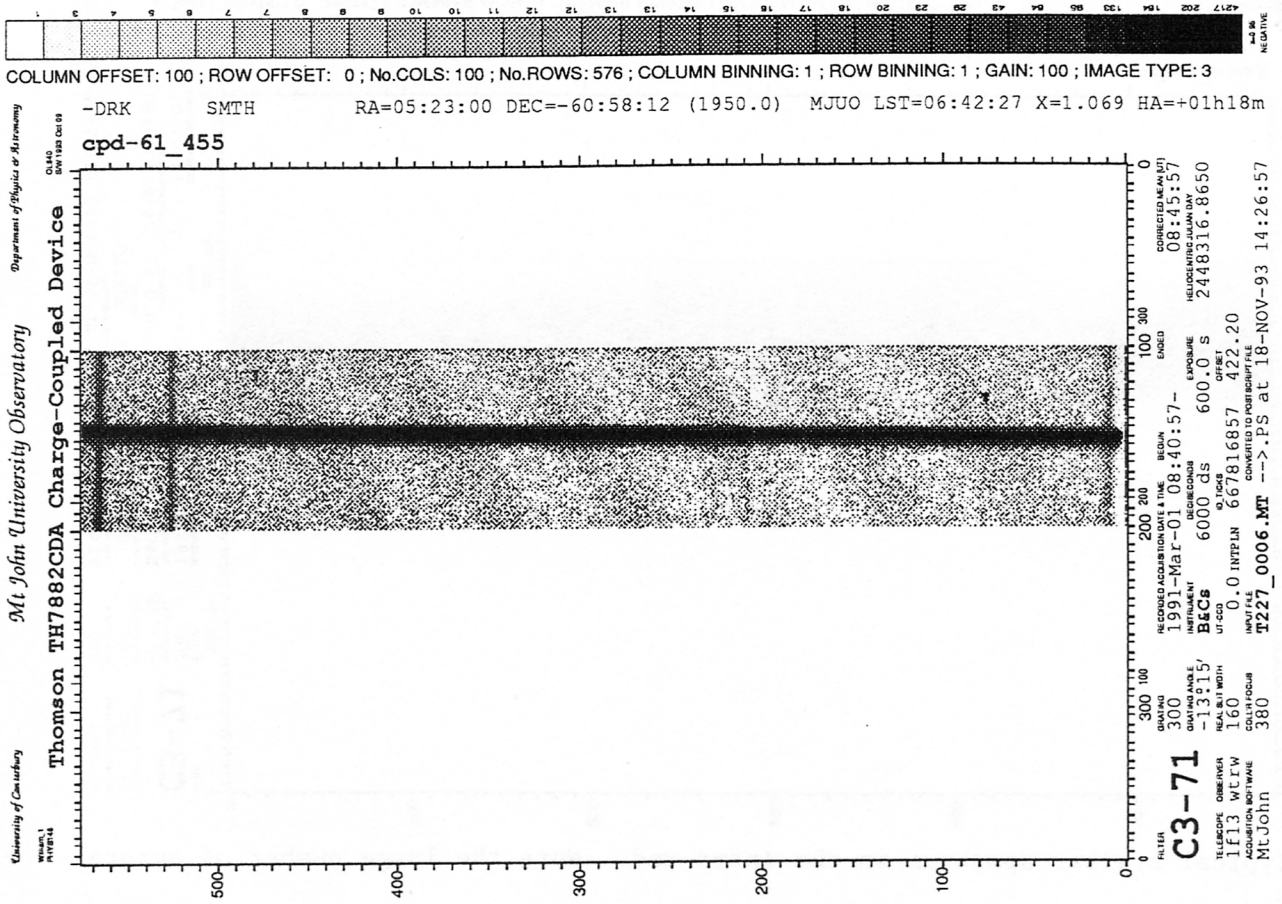
50. Typical stellar spectrum of a bright star.


COLUMN OFFSET: 90 ; ROW OFFSET: 0 ; No.COLS: 100 ; No.ROWS: 576 ; COLUMN BINNING: 1 ; ROW BINNING: 1 ; GAIN: 0 ; IMAGE TYPE: 3
-DRK
RA=05:28:15 DEC=-20:45:34 (2000.0) MJUO LST=09:17:47 X=1.644 HA=+03h49m
Beta_Lep
Mt John University Observatory
Thomson TH7882CDA Charge-Coupled Device
C3-71
T244_0023.MT

51. Typical stellar spectrum in the infra-red. Note the large number of auroral lines.

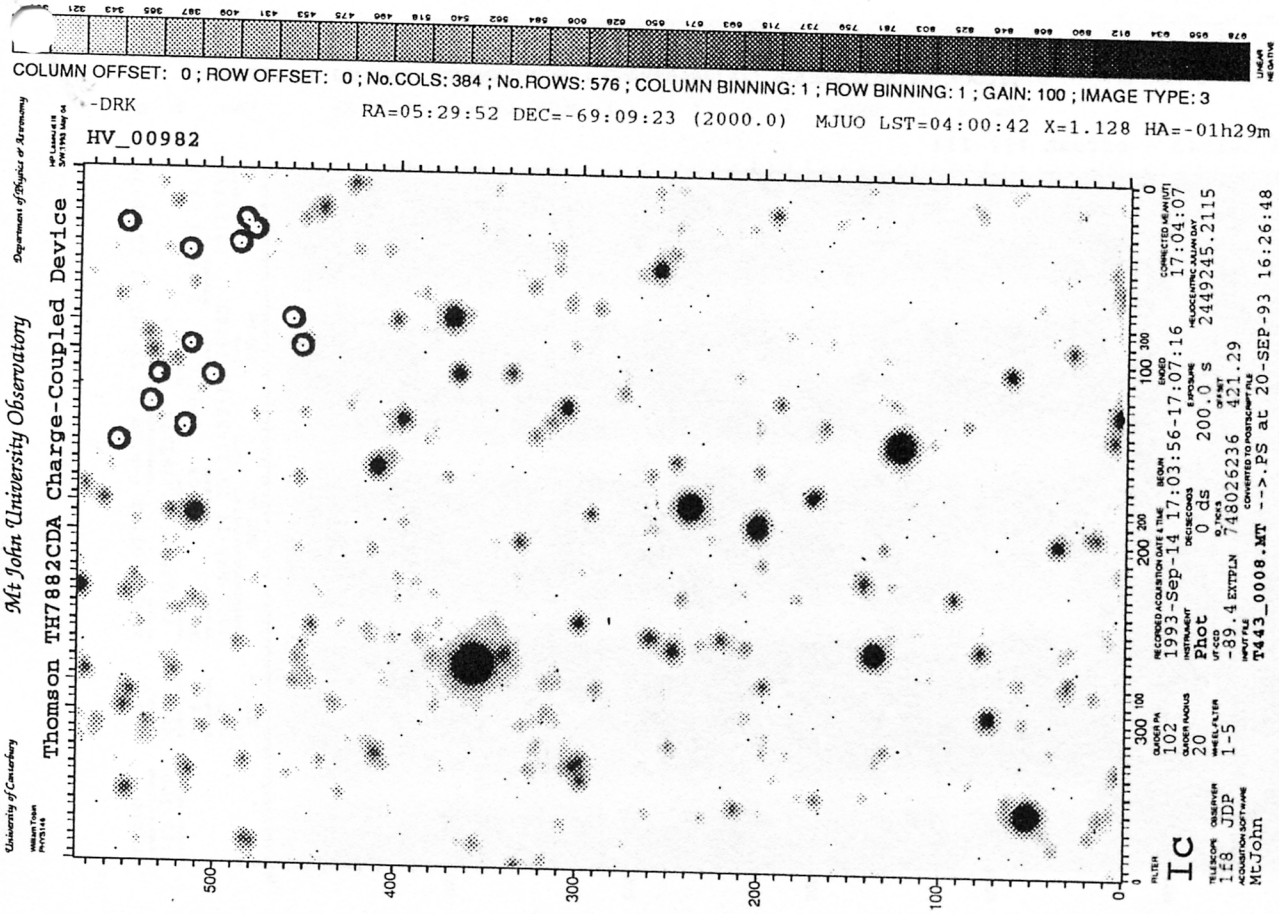

COLUMN OFFSET: 90 ; ROW OFFSET: 0 ; No.COLS: 140 ; No.ROWS: 576 ; COLUMN BINNING: 1 ; ROW BINNING: 1 ; GAIN: 100 ; IMAGE TYPE:15
-DRK
RA=05:23:00 DEC=-60:58:12 (1950.0) MJUO LST=02:35:13 X=1.149 HA=-02h48m
cpd-61_455
Mt John University Observatory
Thomson TH7882CDA Charge-Coupled Device
RG630
T004_0053.MT

52. The a.c. pickup in this spectrum of a faint star is difficult to subtract. The a.c. pickup can be pseudorandomized by reading out a slightly different number of columns or by altering cgain slightly.

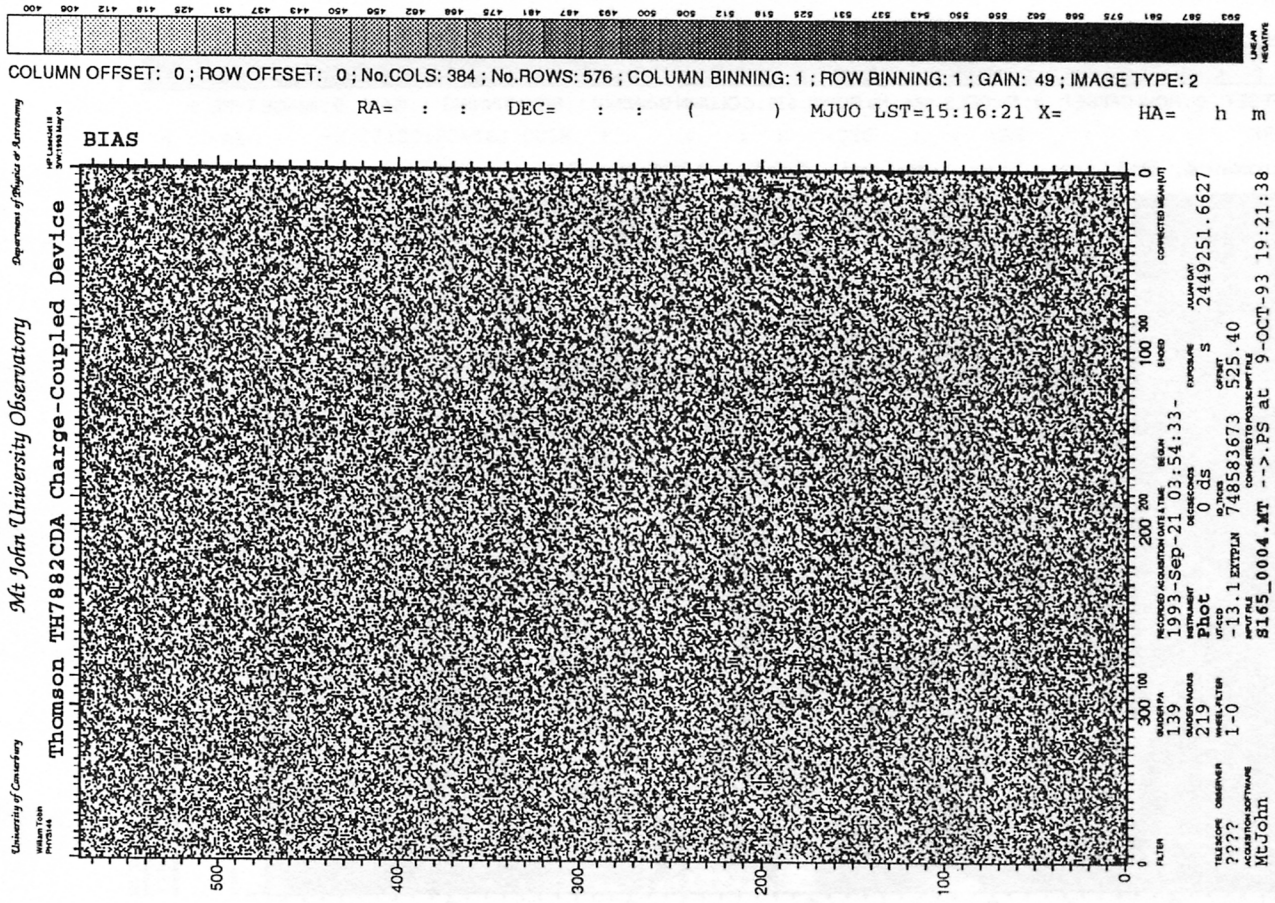


F. MISCELLANEOUS IMAGES.

53. Bright pixels (some circled) appeared erratically on images...

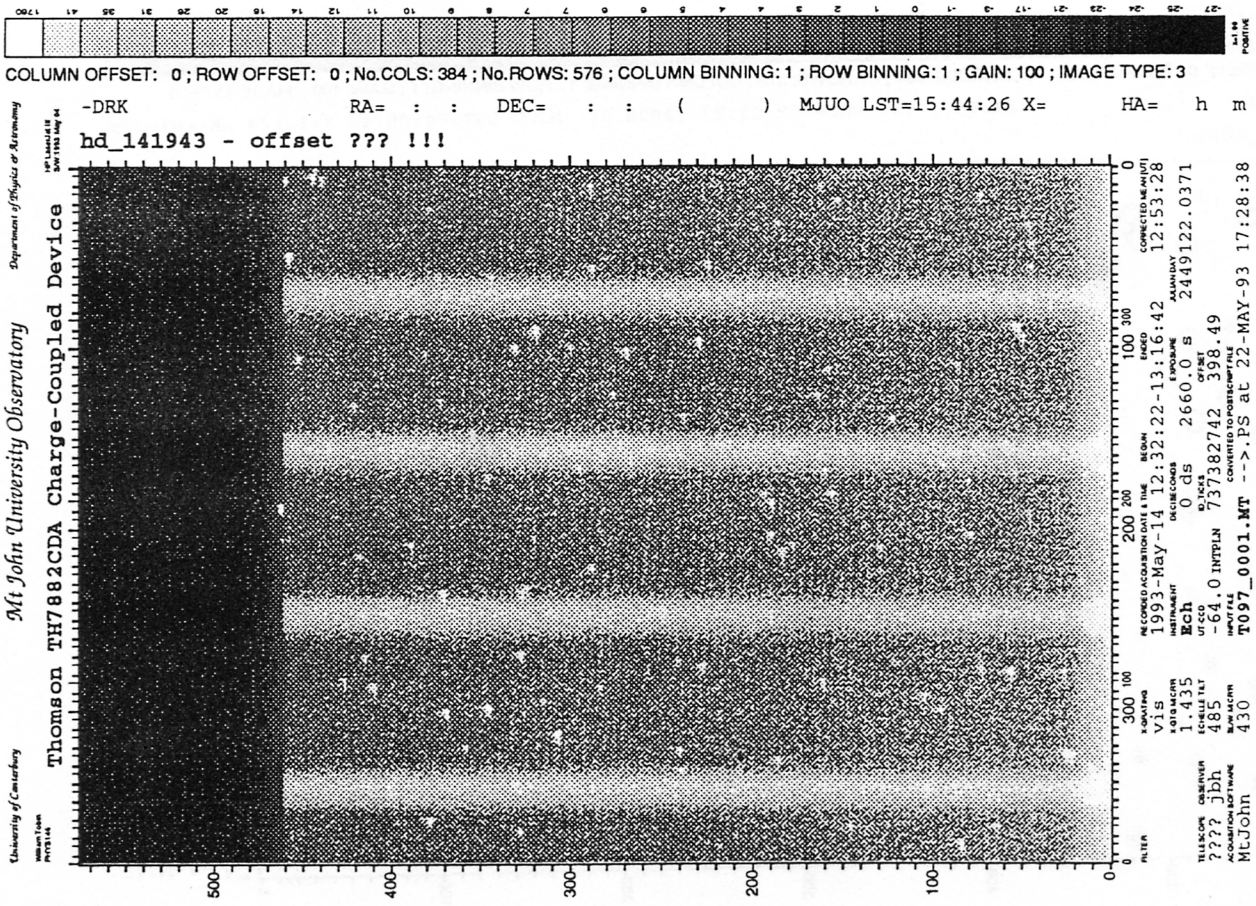

COLUMN OFFSET: 0 ; ROW OFFSET: 0 ; No.COLS: 384 ; No.ROWS: 576 ; COLUMN BINNING: 1 ; ROW BINNING: 1 ; GAIN: 100 ; IMAGE TYPE: 3
-DRK
RA=05:29:52 DEC=-69:09:23 (2000.0) MJUO LST=04:00:42 X=1.128 HA=-01h29m
HV_00982
Mt John University Observatory
Thomson TH7882CDA Charge-Coupled Device
University of Canterbury
Ic
MtJohn
T443_0008.MT -->.PS at 20-SEP-93 16:26:48

54. ...by altering the value of cgain (and therefore the readout rate) it was possible for a large proportion of the pixels to be affected...

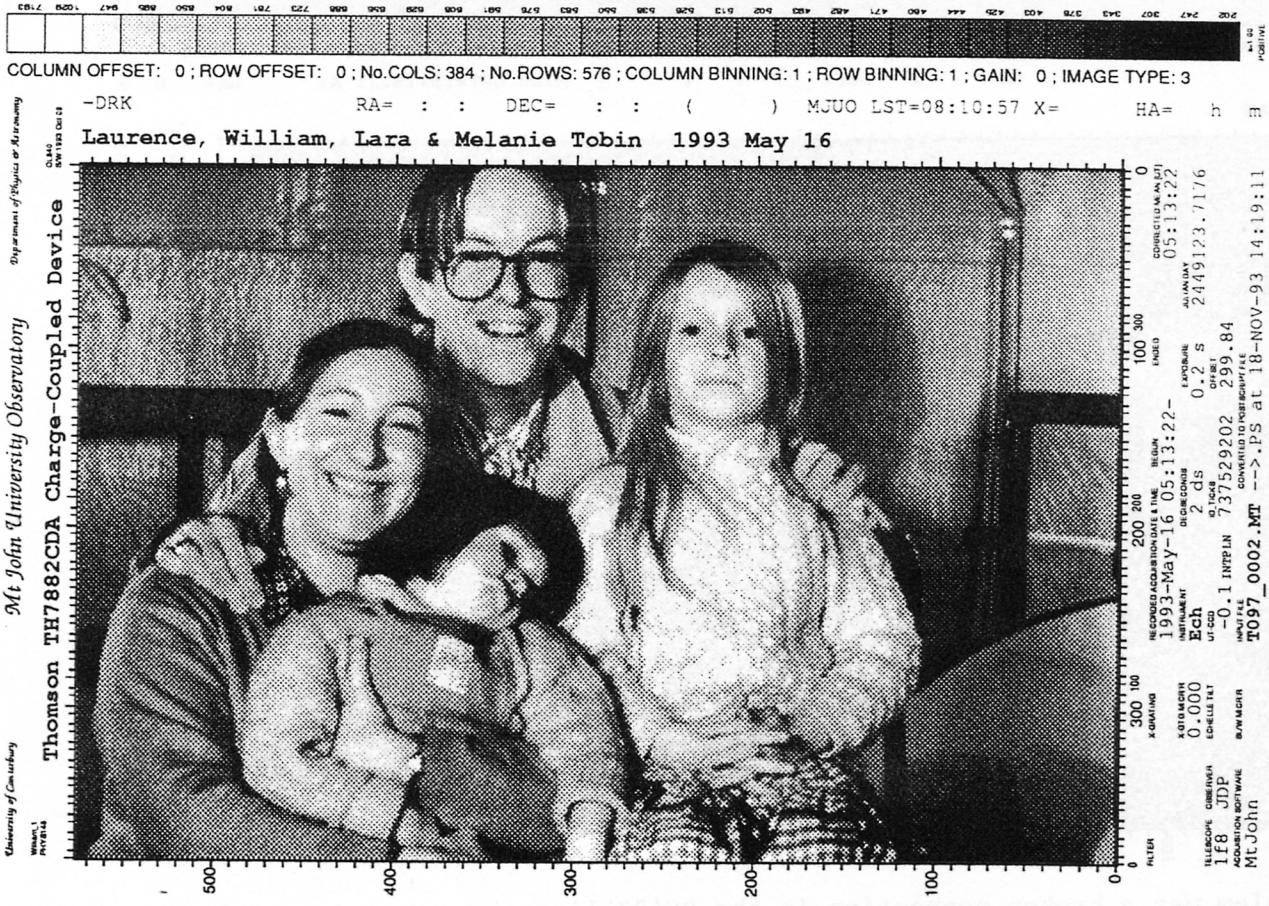

COLUMN OFFSET: 0 ; ROW OFFSET: 0 ; No.COLS: 384 ; No.ROWS: 576 ; COLUMN BINNING: 1 ; ROW BINNING: 1 ; GAIN: 49 ; IMAGE TYPE: 2
RA= : : DEC= : : ( ) MJUO LST=15:16:21 X= HA= h m
BIAS
Mt John University Observatory
Thomson TH7882CDA Charge-Coupled Device
University of Canterbury
MtJohn
S165_0004.MT -->.PS at 9-OCT-93 19:21:38

The problem was a broken connection in the RS422 lines carrying the synchronization clock pulses from the CE200 to the PM3000.

55. The data transfer from CE200 to PM3000 image memory was incomplete.


COLUMN OFFSET: 0 ; ROW OFFSET: 0 ; No.COLS: 384 ; No.ROWS: 576 ; COLUMN BINNING: 1 ; ROW BINNING: 1 ; GAIN: 100 ; IMAGE TYPE: 3
-DRK RA= : : DEC= : : ( ) MJUO LST=15:44:26 X= HA= h m
hd_141943 - offset ??? !!!
Mt John University Observatory
Thomson TH7882CDA Charge-Coupled Device
1993-May-14 12:32:22-13:16:42
Ech
-64.0 INTPLN
T097_0001.MT -->.PS at 22-MAY-93 17:28:38
????? jbh
MtJohn

56.


COLUMN OFFSET: 0 ; ROW OFFSET: 0 ; No.COLS: 384 ; No.ROWS: 576 ; COLUMN BINNING: 1 ; ROW BINNING: 1 ; GAIN: 0 ; IMAGE TYPE: 3
-DRK RA= : : DEC= : : ( ) MJUO LST=08:10:57 X= HA=
Laurence, William, Lara & Melanie Tobin 1993 May 16
Mt John University Observatory
Thomson TH7882CDA Charge-Coupled Device
1993-May-16 05:13:22-
Ech
-0.1 INTPLN
T097_0002.MT -->.PS at 18-NOV-93 14:19:11
1f8 JDP
MtJohn

PHOTOMETRICS 3000

Digital Image Acquisition System

The Photometrics 3000 Digital Image Acquisition System is a complete camera support package with a resident computer for image acquisition, calibration, and storage. The extensive software package provided with the Photometrics 3000 (UNIX™ System V and FORTH operating systems) supports all features of Photometrics cameras.

The desktop or 19-inch rack-mount chassis houses:

- A 5 1/4-inch double-sided double-density 720 kilobyte (formatted) floppy disk drive;
- A 5 1/4-inch 55 megabyte (unformatted) Winchester disk drive;
- A 40 megabyte (formatted) DC2000 cartridge tape drive (1/4-inch tape) with block addressing for program storage and archiving images;
- A camera interface and power supplies to operate any Photometrics Ltd. camera at a distance of up to 200 feet from the Photometrics 3000;
- A nine slot MULTIBUS® card cage.

The first five slots are used by the standard system:

- Card 1: A single board computer with 68020 processor and 68881 math coprocessor daughter board, one megabyte program RAM, floppy disk interface, SCSI Winchester disk interface, general purpose SCSI port, DMA controller, and four serial RS232 ports which support the mouse for cursor activities, a terminal*, an alphanumeric printer*, and a user-defined option. (slots 1 & 2)

- Card 2: A Photometrics-proprietary camera controller board with a bit-slice state machine and a DMA channel for transferring images from the camera to MULTIBUS® memory image buffers.

- Card 3: A monochrome video display board with graphics overlay for viewing images and plotting cross sections and histograms. The 12 or 14 bit camera data are compressed in software to 8 bits based on user-defined minimum and maximum intensities. These 8 bits are then converted to analog RS170 output. A status line at the top of the screen gives the current cursor location and intensity.

- Card 4: A 4 or 8* megabyte RAM image buffer for acquiring and storing images generated by the camera or retrieved from the archive media.

The remaining four slots can be daughter with an additional image buffer RAM board (4 or 8 megabytes) or a variety of user-supported MULTIBUS® - compatible boards, such as color display drivers, high speed image processors, fast Fourier transform boards, and communication links (Ethernet™, GPIB, etc...).

*Priced separately

MULTIBUS is a Trademark of Intel Corporation
Ethernet is a Trademark of Xerox Corporation
UNIX is a Trademark of AT&T Bell Laboratories

CCD Cameras
Digital Imaging Systems

2010 North Forbes Boulevard/Suite 103
Tucson, Arizona 85745
Telephone (602) 623-8961
Telex #823091 PHOTO UF

DOMESTIC PRICE SCHEDULE
Effective Date: December 15, 1987

PHOTOMETRICS 3000
DIGITAL IMAGE ACQUISITION AND PROCESSING SYSTEM

The PHOTOMETRICS 3000 system consists of a computer subsystem and a camera support subsystem.

The computer subsystem consists of:

- 68020 CPU w/68881 math coprocessor (software support, 1st Quarter, 1988)
- Four serial interface ports
- One general purpose SCSI port
- One megabyte of program RAM
- 55 megabyte (unformatted) hard disk drive (Note 1)
- 720 Kilobyte (formatted) 5 1/4 inch floppy disk drive
- 40 megabyte1/4" cartridge tape drive
- Nine-slot MULTIBUS® chassis
- Operating systems: Unisoft UNIX™ System V and FORTH
- On-site installation and introduction to system

Computer Subsystem Price	$18,495.00

The camera support subsystem consists of:

• Camera controller and power supplies	$ 2,400.00
• Image display module w/mouse	2,400.00
• Four megabyte image buffer RAM (Note 2)	1,695.00
• Photometrics camera system software	6,950.00
Camera Support Subsystem Price	$13,445.00
PHOTOMETRICS 3000 SYSTEM PRICE	**$31,940.00**

PHOTOMETRICS 3000 System Upgrades

Notes: 1. Upgrade to 140 megabyte (unformatted) hard disk drive	add $ 3,885.00
2. Upgrade to 8 megabyte image buffer RAM	add $ 1,000.00

PHOTOMETRICS 3000 Options

CRT terminal with RS232 input (for command entry)	$ 825.00
CRT terminal with graphics enhancement (for command entry and display of graphs)	$ 1,950.00
12-inch diagonal high performance monochrome RS170 monitor (for image display)	$ 595.00
Additional four megabyte image buffer board	$ 1,695.00
Additional eight megabyte image buffer board	$ 2,695.00
1/2-inch 9 track tape, 1600 BPI, with formatter, interface, and drivers	$ 8,950.00

Prices subject to change without notice

MULTIBUS is a trademark of Intel Corporation
UNIX is a trademark of AT&T Bell Laboratories

CE200 CAMERA ELECTRONICS UNIT

The CE200 camera electronics unit is designed to be used with all Photometrics Series 200 camera heads. The CE200 receives power from the camera controller and subregulates it to the various voltages required by the camera. AC line input is also required for the thermoelectric cooler power supply and for a small fan. This unit is modular in design with a motherboard and six printed circuit plug-in boards, each with a specific function in the camera head:

- Power supply regulators and distribution;
- Sensor temperature control circuitry;
- Parallel clock generators and drivers;
- Serial clock generators and drivers;
- Analog processing and digitizer; and
- Logic, timing, and other support circuits.

The following analog correlated double sample processor options are offered:

- A variable gain analog card with a 14 bit ADC that operates at 50 kHz; or
- A fixed gain fast analog card with 12 bit ADC that operates at 200 kHz.

The CE200 is designed to be used with the CH210 cryogenically cooled camera head and the CH220 and CH230 thermoelectrically cooled heads. When used with the cryogenic head, a temperature control and digital readout is provided to allow the user to optimize the sensor temperature for maximum performance. When supplied with a thermoelectric head, the temperature setpoint is hard wired to a specific level. The CE200 camera electronics unit may be located up to 200 feet from the camera controller. The camera head must, however, be located within four feet of the camera electronics unit.

CE200 SPECIFICATIONS

Weight: 12 lbs (5.5 Kg.)

Length: 13 inches (33 cm)

Height: 6 inches (15.2 cm)

Width: 6 inches (15.2 cm)

Power provided by the camera controller:
+26 VDC @ .31A
-20 VDC @ .18A
+9 VDC @ .85A

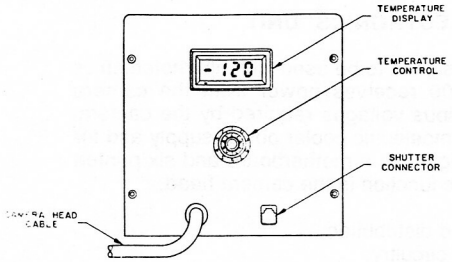
Maximum distance from camera controller: 200 feet (61 m)

Maximum operating temperature: 120°F (48°C)

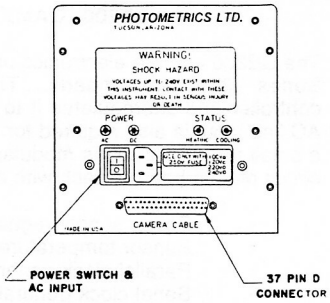
AC line power requirements:
115 VAC or 230 VAC; +5 % - 10 %; 48 - 66 Hz
50VA when used with thermoelectrically cooled head;
7VA when used with cryogenically cooled head

CCD Cameras
Digital Imaging Systems

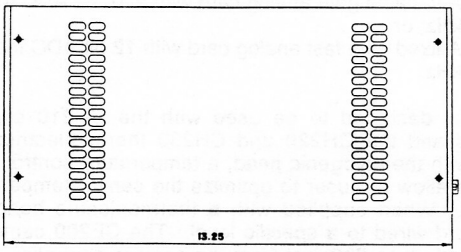
2010 North Forbes Boulevard/Suite 103
Tucson, Arizona 85745
Telephone (602) 623-8961
Telex #823091 PHOTO UF



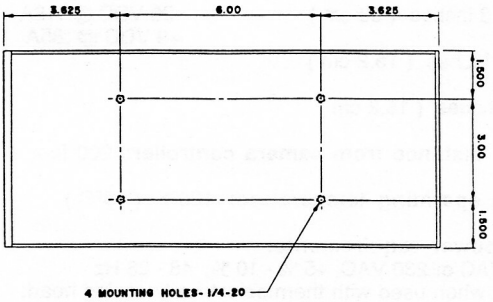
Front View
(Temperature Display & Control
Supplied Only with CH210)



Rear View



Side View



Bottom View

CE200 Mechanical Specifications

The CCD Imager

Figure 1—Frame Transfer CCD Architecture

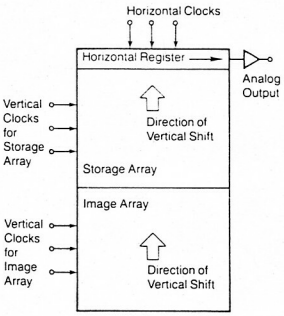
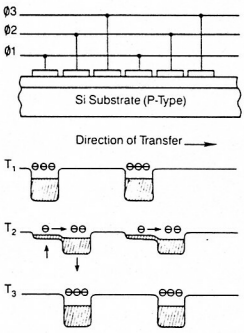


Figure 2—Charge Transfer Mechanism in 3-Phase CCD



A CCD (charge coupled device) imager is a MOS light sensitive device containing up to two square centimeters of active area. A CCD is ususally processed with multi-level polysilicon gates which are biased to produce thousands of independent potential wells over the entire chip. Each potential well is capable of accumulating free charge which is produced when light strikes the immediate area. These independent sites where charge is stored are called pixels (picture elements), and when closely arranged in a rectangle, allow a pattern of charge to accumulate which corresponds to an illumination pattern. Pixels may be square or rectangular and vary from 10 to 30 microns in size.

During an exposure to light, charge accumulates at each pixel in an amount proportional to the light intensity at the site. After sufficient charge has accumulated, the CCD may be read out, that is, the accumulated charge may be transferred in a serial fashion to an output capactive node where a signal is produced which may be amplified and measured. Referring to Figure 1, the readout proceeds with a vertical transfer of charge packets, an entire row at once, into a horizontal register, where they are then clocked toward the output node. The sequence is continued until all the charge has been transformed and the potential wells have been emptied. CCDs are fabricated in many forms depending upon the process used in manufacture and the ultimate application. Figure 2 illustrates the charge transfer concept for a 3-phase charge packet is pushed up the register.

In summary, the CCD is an electronic imaging device which can integrate during an exposure to light and be read out on command. The readout process produces an independent signal from each pixel which is proportional to the light striking the pixel.

The exposure of a CCD to light must be controlled, and the readout must be made after light input has been terminated. If excessive light is allowed to strike the CCD during readout, streaking and pixel contamination will result as the frame is shifted up the vertical register. Two methods are used to control exposure. The first is simply an electro-mechanical shutter similar to ones found in conventional film-type cameras. The second method requires the use of the upper half of the CCD as a storage area.

Referring to Figure 1, note that the CCD is made up of two identical sections called the image and storage arrays. The storage may be covered with an opaque mask so that the light will only strike the image array. After an exposure is made on the image array, the entire frame is rapidly transferred to the storage array. While the masked storage array is being read out, the image array may integrate the next frame. This method of readout will operate with negligible picture degradation if the time to transfer the frame from the image array to the storage array is short compared to the exposure time. This readout mode may be used in a continuous fashion with each storage frame readout occuring during image frame exposure.

A CCD constructed with separate image and storage arrays is called a frame transfer device. Note that the image and storage arrays are identical in nature and both may be used in an imaging mode if a shutter is used. In certain applications where the exposure time is very long relative to full readout of image and storage arrays, the shutter may not be required.

If the light illuminating the CCD must pass through the multi-level polysilicon gates before reaching the silicon surface, considerable absorbtion will occur especially at short wavelengths. A method of improving sensitivity and eliminating this loss is to thin the silicon and focus the optical image on the backside of the CCD. Thinned devices are produced which exhibit quantum efficiences near unity. Low noise, geometric stability and high sensitivity highlight CCD performance.

CCD Cameras
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PHOTOMETRICS LTD.
2010 N. Forbes Blvd.
Tucson, AZ 85745 -1418 U.S.A.
(602) 623-6992 TELEX 823091 PHOTO UF
FAX (602) 791-3987

CONFIRMATION OF PURCHASE ORDER

Date Order Received: September 7, 1988
P.O. #75571
Photometrics Job #88-166
Photometrics Quotation #1519a
Estimated Shipping Date: Dependent Upon Obtaining Export License and Letter of Credit
Method Of Shipment: D.H.L. Worldwide Express, Prepaid (Insure)
Terms: Letter of Credit
Warranty: Six Months from Shipping Date

BILL TO:
University of Canterbury
Private Bag
Christchurch
New Zealand

SHIP TO:
University of Canterbury
Private Bag
Christchurch
New Zealand

Buyer: A.W. Hayward and F.N. Johnson FAX (011) (64) (3) 430-326
End User: Dr. William Tobin (011) (64) (3) 482-009, Extension 7531

Changes Made After Acceptance of This Order May Incur Restocking Charges.

Item	Description	Qty	Unit Price	Total
	Photometrics 3000 Digital Image Acquisition and Processing System Consisting of:			
1	Computer Subsystem Consisting of: 68020 CPU with 68881 FPP - Four Serial Interface Ports - One General Purpose SCSI Port - One Megabyte of Program RAM - 55 Megabyte (unformatted) Hard Disk Drive - 720 Kilobyte (formatted) 5-1/4-Inch Floppy Disk Drive - 40 Megabyte (formatted) 1/4-Inch Cartridge Tape Drive - Nine-slot MULTIBUS® Chassis - Operating Systems: Unisoft UNIX™ System V and FORTH	1	$20,345.00	$20,345.00
	Camera Support Subsystem consisting of:			
2	Camera Controller and Power Supplies	1	2,640.00	2,640.00
3	Image Display Module with Mouse	1	2,640.00	2,640.00
4	Eight Megabyte Image Buffer RAM	1	4,285.00	4,285.00
5	Photometrics Camera System Software	1	7,645.00	7,645.00
6	PM3000 110V Power Cord	1	N/C	
7	Camera Cable, 20 Ft.	1	33.00	33.00
8	Extra Camera Cable, 35 Ft.	1	192.50	192.50
9	Extra Camera Cable, 100 Ft.	1	407.00	407.00
10	PM3000 User's Manual	1	N/C	
11	PM3000 FORTH Manual	1	N/C	
12	PM3000 UNIX™ Manual	1	N/C	
	Subtotal for PM3000 System			$38,187.50
13	CH210 Camera Head, Cryogenically Cooled, Bottom-Looking	1	10,945.00	10,945.00
14	Thomson CSF TH7882CDA CCD, Grade A, Installed	1	2,640.00	2,640.00
15	METACHROME™ II Ultraviolet Response-Enhancement Coating Applied to Item 14	1	2,090.00	2,090.00
	Subtotal for CH210 Camera Head			$15,675.00

ALL PRICES IN U.S. DOLLARS

Customer Inquiries: Beckie Strahan
(602) 623-6992

Authorized By: _____
Gary McAnally, Sales Manager

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Tucson, AZ 85745 -1418 U.S.A.
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Method Of Shipment: D.H.L. Worldwide Express, Prepaid (Insure)
Terms: Letter of Credit
Warranty: Six Months from Shipping Date

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Buyer: A.W. Hayward and F.N. Johnson FAX (011) (64) (3) 430-326
End User: Dr. William Tobin (011) (64) (3) 482-009, Extension 7531

Changes Made After Acceptance of This Order May Incur Restocking Charges.

Item	Description	Qty	Unit Price	Total
16	CE200 Camera Electronics Unit with 50 kHz Analog to Digital Conversion (14 Bits)	1	8,140.00	8,140.00
17	CE200 110V Power Cord	1	N/C	
	Subtotal for CE200 Camera Electronics Unit			$8,140.00
18	12-Inch Diagonal High Performance Monochrome RS170 Monitor	1	655.00	$655.00
19	CRT Terminal with Graphics Enhancement	1	2,855.00	$2,855.00
	TOTAL CAMERA/COMPUTER SYSTEM PRICE			$65,512.50
20	3% Discount for Order Over $30,000.00			<$1,965.00>
	DISCOUNTED TOTAL			$63,547.50
21	Approximate Dimensions and Weights of Shipping Containers: 1 Crate, Approximately 3' X 3' X 4', Weighing 175 Lbs. 1 Crate, Approximately 3' X 3' X 4', Weighing 200 Lbs.			
22	Freight Charges from Tucson, Arizona, U.S.A. to Christchurch, New Zealand (D.H.L. Worldwide Express)		2,200.00	$2,200.00
23	Insurance ($.50 Per $100 Insured Value, Fireman's Fund)		315.00	$315.00
	PRICE INCLUDING FREIGHT AND INSURANCE			$66,062.50

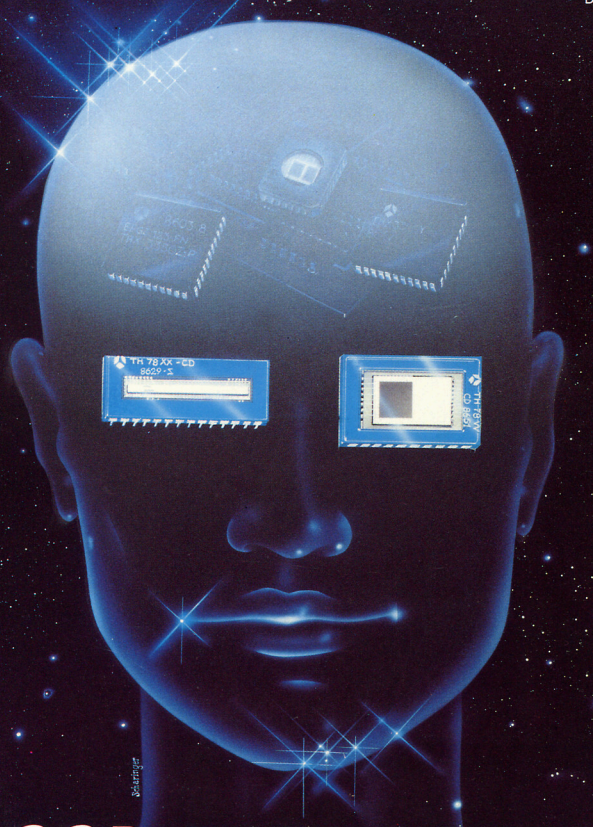
NOTES:
1. System to be configured to operate at 230V, 50 Hz.
2. Price above is for items listed above and none other. Price quoted and confirmed does not include bank charges necessary for customer to arrange Letter of Credit.

ALL PRICES IN U.S. DOLLARS

Customer Inquiries: Beckie Strahan
(602) 623-6992

Authorized By: Gary McAnally, Sales Manager

DTE 146



CCD DATA BOOK

THOMSON-CSF
DIVISION SILICIUM

BRANCHE
COMPOSANTS SPÉCIAUX

THOMSON-CSF
DIVISION SILICIUM

BRANCHE
COMPOSANTS SPÉCIAUX

CCD DATA BOOK - 1988

Single Field Area Array CCD* Image Sensor

576 x 384 Pixels

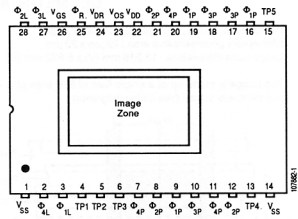
- **Image Zone : 13,25 x 8,83 mm**
- **4-phase operation (Dynamic Range : 5000/1)**
- **Optimized Resolution and Responsivity in the 400-1100 nm Spectrum (Visible + Near Infrared)**
- **Output Noise : 10 Electrons (50 Khz and - 40°C)**
- **Minimum Readout Time = 25 ms (for entire field)**
- **High Contrast : 60 % Modulation at Nyquist Frequency**
- **Unity Gamma**
- **Low Aliasing (moiré)**
- **Square Pixels (23 µm x 23 µm)**
- **Dark Reference for Each Line**

The TH 7882 provides a high degree of sensitivity thanks to its very uniform dark signal. Furthermore, its special semiconductor process gives a particularly good performiance in the near infrared spectrum.

This sensor uses a buried channel design and two-level polysilicon n-MOS technology.

The TH 7882 is directly derived from TH 7861 device the storage zone of which is transformed into an image area, adjacent and identical to the original image zone. It provides a single-field image and consequently is not compatible with TV standards.

* Charge Coupled Device



PIN IDENTIFICATION

Pin n°	Symbol	Designation
(9 - 16 - 19) (8 - 12 - 21) (10 - 17 - 18) (7 - 11 - 20)	$\Phi_{1P} \rightarrow \Phi_{4P}$	Image-Zone Clocks
3-28-27-2	$\Phi_{1L} \rightarrow \Phi_{4L}$	Readout Register Clocks
25	Φ_R	Reset Clock
22	V_{DD}	Output Amplifier Drain Supply
24	V_{DR}	Reset Bias
1,14	V_{SS}	Substrate Bias
26	V_{GS}	Register Output Gate Bias
23	V_{OS}	Video Output Signal
4-5-6-13-15	TP1 to TP5	Test Points

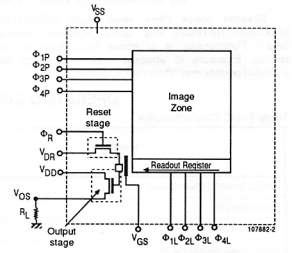


Figure 1 - TH 7882 Organization

GEOMETRICAL CHARATERISTICS

Photoelement pitch (see figure 2) : 23 µm x 23 µm
Elementary photosensitive area : 23 µm x 23 µm
Image zone dimensions : 13.248 mm (V) x 8.832 mm (H)

The image is made up of a single field of 576 lines plus 4 extra lines. The video line is composed of 384 useful pixels, and 405 elements in total (see timing diagrams).

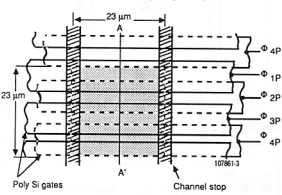


Figure 2a - Plan view of a photoelement

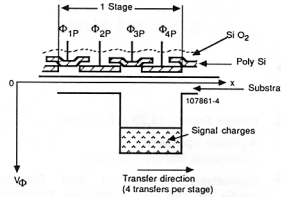


Figure 2b - Cross-sectional view (AA') of a photoelement and potential profile during transfer

Absolute Maximum Ratings

Storage Temperature ..... - 55°C to + 150°C
Operating Temperature ..... - 40°C to + 125°C
Maximum applied voltages :
- reference voltage ..... 0V(ground)
- pins 6, 13, 15, 22, 24 ..... - 0.3 V to + 18 V
- pins 2, 3, 7, 8, 9, 10, 11, 12, 16, 17, 18, 19, 20, 21, 25, 26, 27, 28 ..... - 0.3 V to + 15 V
- pins 1, 4, 5, 14 ..... V_{SS} (- 5 V to 0 V)
Thermal cycling ..... 3°C/mn (30°C/mn between -25°C and + 70°C)

Stresses above those listed under ABSOLUTE MAXIMUM RATINGS may cause permanent device failure. Functionality at or above these limits is not implied. Exposure to absolute maximum ratings for extended periods may affect device reliability.

Operating Ranges

Operating ranges define the limits between which the functionality is guaranteed.

These limits are given in the ORDERING CODES section.

Operating Precautions

Shorting the video output to V_{SS} or V_{DD}, even temporarily, can permanently damage the output amplifier.

OPERATING CONDITIONS (T = 25 °C)

Table I - DC Characteristics

Parameter	Symbol	Values			Unit
		Min.	Typ.	Max.	
Output Amplifier Drain Supply	V_{DD}	15	15.5	16	V
Reset Bias (1)	V_{DR}	12	13	14	V
Substrate Bias (1) (2) Pin 1 - 14	V_{SS}	- 2.5	- 1.0	0.0	V
Output Load Resistance (3)	R_L	1	2.2	-	kΩ
Register Output Gate Bias	V_{GS}	2.0	2.5	3.0	V
Test Points 1 and 2	TP1, TP2	-	V_{SS}	-	V
Test Points 3 and 5	TP3, TP5	-	V_{DD}	-	V
Test point 4	TP4	8	9	10	V

(1) Adjustment required for optimum performance
(2) V_{SS} = 0 V requires that the drive clocks, loaded by the device, do not contain spurious negative spikes (less than - 0.1 V)
(3) At a low output frequency, the load resistance may be increased in order to lower power consumption and noise (resulting from amplifier bandwidth limitation).

Table II - Static and dynamic electrical characteristics

Parameter	Symbol	Value		Unit	Conditions
		Typ.	Max.		
DC Output Level	V_{ref}	6.5	-	V	
Output Impedance	Z_S	1500	-	Ω	
Output Amplifier Supply Current	I_{DD}	3	10	mA	$V_{DD}= \Phi_R = V_{DR}= 15$ V $R_L = 2.2$ kΩ $V_{SS} = 0$ V
Input Current on an Active Pin (except for V_{DR} and V_{DD})	I_e	-	2	µA	$V_e = 15$ V $V_{SS} = 0$ V
Average Current Sink on Φ_P Clocks	I_P	0.4	-	mA	Under Typical Operating Conditions
Average Current Sink on Φ_L Clocks	I_L	15	-	mA	
Peak Current Sink on one Clock (Φ_P or Φ_L)	$I_{P\text{-}P\Phi}$	300	-	mA	

Table III - Drive clock characteristics

Parameter	Symbol	Value			Unit	Remarks
		Min.	Typ.	Max.		
Image Zone Clocks During Integration Period						
	Φ_{1P}, Φ_{2P}	9	10	11	V	$C\Phi_{1P} = C\Phi_{2P} =$ $C\Phi_{3P} = C\Phi_{4P} =$ 4000 pF
	Φ_{3P}	0.0	0.3	0.5	V	
	Φ_{4P}	1.5	1.8	2.0	V	
OR						
	Φ_{1P}	0.0	0.3	0.5	V	
	Φ_{2P}	1.5	1.8	2.0	V	
	Φ_{3P}, Φ_{4P}	9	10	11	V	
Image Zone Clocks During Transfer Period	(Φ_P) Low	0.0	0.3	0.5	V	
	(Φ_P) High	9	10	11	V	
Output Register and Reset Clocks :						
- Low (L)	(Φ_L, Φ_R)L	0.0	0.3	0.5	V	$C\Phi_{1L} = C\Phi_{2L} = C\Phi_{3L} =$ $C\Phi_{4L} = 75$ pF $C\Phi_R < 5$ pF
- High (H)	(Φ_L, Φ_R)H	9	10	11	V	
Maximum Image → Output Register Frequency	F_I	0.92	2	-	MHz	
Max. Ouput Register and Reset Frequency	F_L	7.38	10	-	MHz	

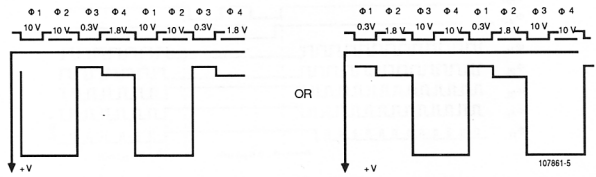


Figure 3 - Image zone potential wells during integration period

TIMING DIAGRAM

The principle of interlacing, shown in figure 3, can be applied to this device. It consists in shifting the potential wells by half a pixel in alternate fields. Thus two successive fields contain different information, giving a 1152-line image with reduced aliasing.

Device operation generally begins with a "cleaning" period, which consists in transferring and eliminating all charges created by thermal generation. Once emptied, each pixel can accumulate charges in proportion to incident light during the integration (exposure) period.

After that time, no luminous event must reach the image zone, in order to prevent smearing effects during the image readout period. This configuration is achieved either with a shutter, either because no light is emitted during the readout time. The 580 lines are then transferred, line by line, into the output register. During each transfer, register clocks are frozen. The total number of transfer periods is at least 580.

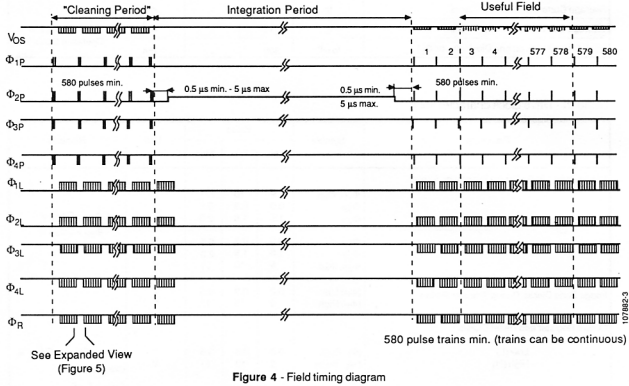


Figure 4 - Field timing diagram

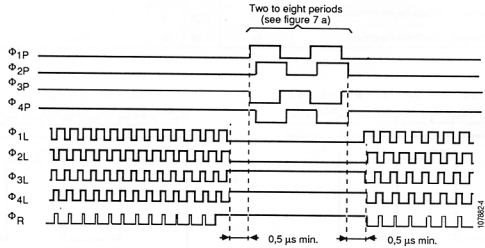


Figure 5 - Expanded view

After parallel transfer into the readout register, the video line is transfered sequentially to a single output circuit. The minimum number of drive clock pulses (405) corresponds to the number of register stages.

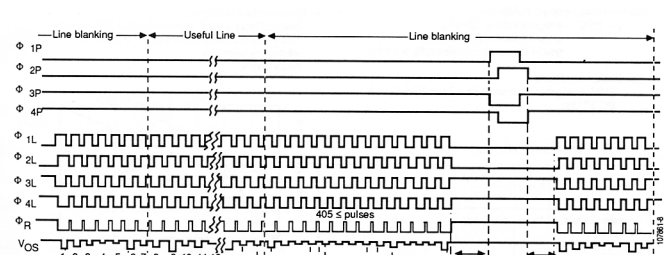
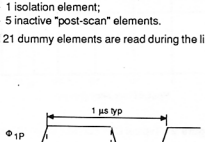


Figure 6 - Line timing diagram

The video line comprises :

1 - 5 inactive "pre-scan" elements;
2 - 2 isolation elements;
3 - 384 useful video pixels;
4 - 4 isolation elements;
5 - 4 dark reference elements (element 396 to 399);
6 - 1 isolation element;
7 - 5 inactive "post-scan" elements.

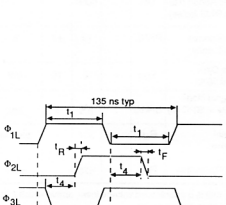
All 21 dummy elements are read during the line blanking period.



30ns ≤ t_R ; 30ns ≤ t_F ;
t ≥ 50ns

Crossover of complementary clocks (Φ_1 and Φ_3, Φ_2 and Φ_4) in the high state (above 90% of max. amplitude)

Figure 7a - Output timing diagram for Φ_P clocks during transfer



10ns ≤ t_R ; 10 ns ≤ t_F
t_1 ≥ 50 ns ; t_2 ≥ 40 ns ; t_3 ≥ 5 ns ;
t_4 ≥ 15 ns ; typical t_5 = 30 ns

Crossover of complementary clocks (Φ_{1L} and Φ_{3L}, Φ_{2L} and Φ_{4L}) preferably between 50 and 100 % of max. amplitude.

Figure 7b - Output timing diagram for readout register and reset clocks

ELECTROOPTICAL PERFORMANCE

- General measurement conditions:
  Tp = 25°C - Integration time : 20 ms ;
  Output frequency : 7,38 MHz
  typical operating conditions; R_L = 2.2 kΩ

- Illumination conditions
  2854 K tungsten filament lamp + 2 mm thick Schott BG 38 filter

- Measurement excludes :
  - first and last pixels of useful video line (n°8 and 391)
  - first and last lines of useful field (n° 3 and 578)
  - all dummy elements
  - faulty pixels.

Table IV - Performance characteristics

Parameter	Symbol	Value			Unit	Remark
		Min.	Typ.	Max.		
Saturation Output Voltage (4)	V_{SAT}	300	500	-	mV	
Saturation Exposure	E_{SAT}	-	0.17	-	µJ/cm²	
Saturation Illumination	L_{SAT}	-	38	-	lux	
Responsivity	R	1.8	3 13	-	V/µJ/cm² mV/ lux	See figure 8
rms Noise in Darkness (5)	V_N	-	0.1	-	mV	
Dynamic Range (Relative to RMS Noise)	DR	-	5000	-		
Photo-response Non-Uniformity	PRNU	-	±4	±7	%	$\overline{V}_{OS}$ = 100 mV
Average Dark Signal at 50°C	V_{DS}	-	2	10	mV	
Dark Signal Non-Uniformity at 50°C (6)	DSNU	-	0.5	4	mV	
Horizontal Resolution	R_{eH}	-	384	-	pts/line	See figure 9
Vertical Resolution	R_{eV}	-	576	-	lines	

(4) V_{SAT} min is a guaranteed voltage level, above which local saturation or non-linearity can occur.
(5) 1mV = 1800 electrons or 1.6 nA.
(6) Excludes non-uniformity due to image zone readout

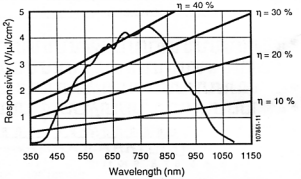


Figure 8 - Typical spectral response

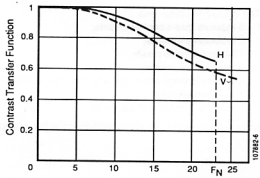


Figure 9 - Typical CTF curves ($\overline{V}_{OS}$= 100 mV)

ELECTROOPTICAL PERFORMANCE WITHOUT INFRARED CUTOFF FILTER

The TH 7882's special semiconductor process enables it to exploit the silicon's high near infrared sensitivity while maintaining good imaging performance in terms of response uniformity and resolution. Changes in performance with and without IR filtering are summarized below.

	With IR cutoff filter	No IR cutoff filter
Average Video Signal Due to a Given Scene Illumination	V_{OS}	V_{OS} x 8
Photo Response Non-Uniformity	± 4 %	± 4 %
CTF at Nyquist Frequency	60 %	40 %

IMAGE QUALITY GRADES

Please consult the product selection guide DTE 119

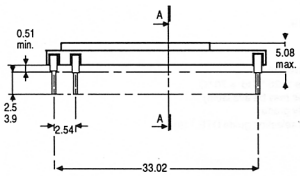
ORDERING CODES

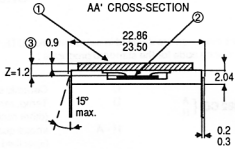
Product markings are detailed in selection guide DTE 119.
The ordering code for the standard product is :

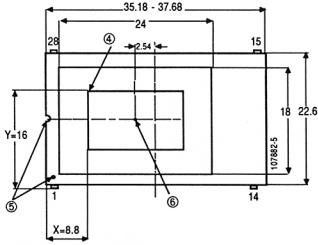
TH 7882 CD { A / H

C.....	:	Ceramic substrate
D.....	:	Temp. range : - 25 °C to + 70 °C (other ranges may be available)
H - A.....	:	Image quality grade (specified in selection guide DTE 119)

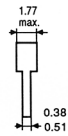
OUTLINE DRAWING







PIN DETAIL



Dimensions in mm

① Window
② Photosensitive area
③ Optical distance between external face of window and photosensitive area
④ First pixel of first line (X,Y,Z coordinates)
⑤ Index (notch or dot)
⑥ Optical center